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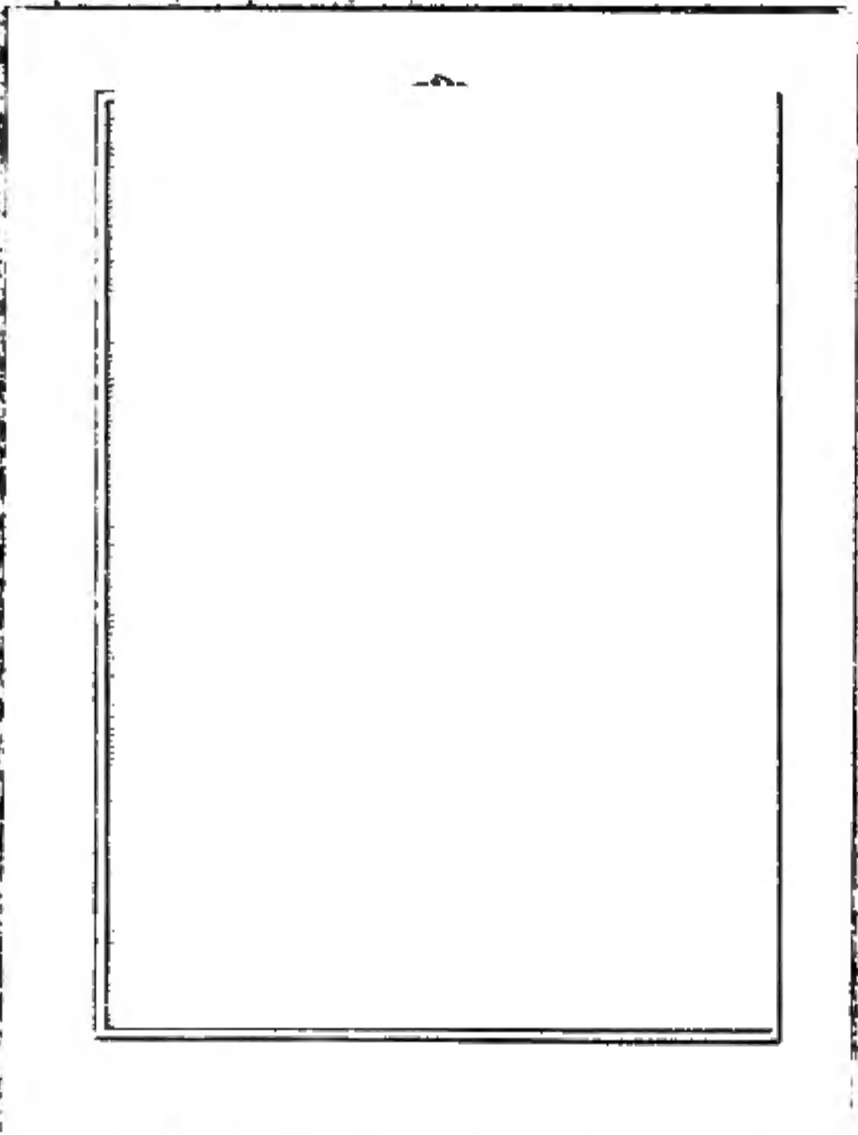
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THE  
ECONOMY OF NATURE.

EXPLAINED AND ILLUSTRATED

ON THE

PRINCIPLES

OF

MODERN PHILOSOPHY.

BY  
G. GREGORY, D.D.

JOINT EVENING PREACHER AT THE FOUNDLING HOSPITAL,

AUTHOR OF

*ESSAYS HISTORICAL AND MORAL, &c.*

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IN THREE VOLUMES.  
WITH FORTY-SIX PLATES.

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VOL. I.

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## P R E F A C E.

**T**HE want of a popular treatise of philosophy, one which might serve as a proper introduction to natural history; to explain to general readers the great principles and operations of nature; to give, in a united view, the discoveries of the moderns on these important subjects, first suggested to me the present undertaking.

It is now many years since I projected this work, and I intended to have termed it, "The Philosophy of Natural History."—In that title I have been anticipated; but my plan, though long since announced very amply to the public, has not yet been anticipated, and the work is still as much wanted as when I first conceived the intention of undertaking it.

To distinguish certainty from conjecture is the most difficult task of the scholar; a task which few find leisure, fortitude, or attention to complete. In the present imperfect state of knowledge, when I say *certainty*, I perhaps would confine the researches of human wisdom within too narrow limits; and *probability* may be the more suitable expression, which must, indeed, comprehend no inconsiderable portion of our discoveries in nature. To separate, therefore, the probable from the fanciful, was my first object; and, if I was not apprehensive of being thought too assuming, I would add, the *useful* from the speculative. I have observed, that in all sciences the principal difficulties arise from certain controverted and disputable points, which are of little importance in themselves, and which, as they are not established upon competent evidence, are not easy to be comprehended.

To expect much of novelty in the following pages, would be to expect falsehood and absurdity. One man, even with the unparalleled

talleled powers of a Newton, is able in the course of his life to make but few discoveries of importance ; and after the toil of centuries, it would be extraordinary if much of what is really true was left to be discovered. If I have succeeded in placing in a clear and perspicuous light the observations of others ; if I have collected, and arranged in a lucid order, the leading truths in the different branches of philosophy, I have performed a great task ; but this I dare not flatter myself I have been able to accomplish.

Imperfect, however, as the work must, I am confident, still appear—it is yet the labour of some of the most valuable years of my life, with the assistance of some learned and excellent friends, whose kindness in these instances I shall have presently to acknowledge more at large. Let those who may be disposed to complain that more has not been done, only reflect on the difficulty of what has been effected, and I flatter myself they will receive with candour an attempt, in which not to

have succeeded would scarcely reflect disgrace on talents inferior to mine.

I have endeavoured to lay open the whole book of nature to my readers. I commence with the first principles of philosophy, the laws of matter and motion, with an enumeration of the most simple or elementary substances. I proceed from these to explain the nature and phenomena of that most active and subtle of elements, heat or fire, which is so intimately connected with all other substances. The theory of light and colours, so immediately dependant on the preceding subject, succeeds ; and this is followed by a short treatise of electricity. The different species of airs, and the atmospherical phenomena, are next treated of ; these are succeeded by a description of the earth and mineral kingdom, and the most remarkable phenomena connected with them, such as volcanoes, earthquakes, &c. The nature and composition of water, with a short account of mineral waters, and of the general properties of that fluid, occupy the next department of the work.

From



From these subjects I have proceeded to what is called the vegetable kingdom, including what is known on the nature and theory of vegetation. The animal economy succeeds; and that as little as possible might be wanting to complete the course of elementary knowledge, I have concluded by a sketch of the human mind. This latter part will connect properly with my *Essays Historical and Moral*, published some years ago, and which contain the great outlines of my sentiments on moral and political philosophy.

As it was my desire to make this treatise as plain and clear as possible to unlearned persons, I have to apologize to my more scientific readers for the occasional repetition of the same principles and observations. Having been, in some measure, all my life engaged in the business of education, I have seen the necessity of frequently recalling the attention of young persons to principles already proved and established, in order to enable them to understand what is to be taught. In giving

the history of different sciences also, many facts and observations are naturally anticipated ; and yet it becomes absolutely necessary to confirm, illustrate, and apply these in a more extensive manner, in treating of the sciences at large.

I have omitted astronomy, because I thought it right to confine my view of nature to our own world ; and because, while Derham's, Ferguson's, and Bonnycastle's writings on that subject are extant, there is no want of a good and popular treatise. I have entered but little into mechanics, because the construction of machines is rather the work of art than of nature \* ; and where I have been obliged, in illustration of any principle, to describe certain well-known machines or engines, I have, for that reason, frequently extracted the description from some popular writer.

\* The Reader will find all these topics, and indeed almost every thing relating to what is termed experimental philosophy, excellently explained in Mr. Nicholson's very useful and accurate Introduction to Natural Philosophy.

If

If it is asked, for whose use this work is designed? I answer, for all whose curiosity would lead them to take a general survey of nature—for all, in particular, who wish to understand the elements and principles of natural history. I conceive also, that it will not be unuseful to the younger students of medicine, as it is intended as an easy introduction to general science; and as it comprehends all the first principles of chemistry and physiology. With the more enlightened class of female readers, I cannot but flatter myself that the work will be favourably received, as I really had their entertainment and information principally in view in compiling it; and they may depend upon it, that there is not a single expression in the whole that can reasonably offend the most delicate and modest ear.

To some persons, who, I must observe, have rather more zeal than knowledge, studies such as these may appear rather inconsistent with the clerical profession and the science of theology, a science extensive enough, I confess,

fess, to occupy the life of a man. I might reply by a simple fact, that *I never yet have been enabled to gain, by the exercise of my profession, a livelihood for myself and family*; and it must appear a hard case to confine the whole attention of any man to what will not furnish him with the necessaries of life; yet the great bulk of my previous publications (without excepting my Essays) have been in the direct line of my profession. I do not, however, rest my apology upon this argument, but I must say, that in publishing the present work, I believe I am not less essentially serving the cause of religion, than if I had been employed in compiling a treatise of divinity. Next to the study of the scriptures, there is none which seems to lead the human mind so directly to a knowledge of its Creator, as the study of nature. In an age therefore when atheism is publicly professed by some, and privately but sedulously disseminated by others, I cannot but hope that a work like the present may have some good effects; and though I have not, like an emiphi-  
 philosopher of the clerical profession,  
 and it a physico-theology, the reader will  
 perceive

perceive that this application of the history of nature has not been forgotten.

As I have no great cause to be intoxicated with my success in life; and as I am verging upon that period when man has little to hope or fear in this world, I feel that it is no affectation to say, I am not extremely solicitous for literary fame; yet I will not dissemble, that I would, if possible, deprecate on the present occasion the severity of criticism, both because I would wish my publisher to be indemnified, since my very limited means will not admit of publishing on my own account; and because I would not wish those friends who have generously afforded me assistance in the present work, to suffer any uneasiness from the harshness of censure, or by my solicitations to have been drawn into a disagreeable predicament.

It remains to do justice to these friends. "To render honour to whom honour is due; praise to whom praise," is the part not only of the christian, but of every honest man. In the optical part of this work I have been materially

terially assisted by a gentleman of known and distinguished abilities, who taught publicly for a series of years the several branches of natural philosophy, but who will not permit me to make my acknowledgments in a more particular manner. For, I may say, the whole of the animal economy, I am indebted to my valuable and scientific friend Dr. Belcher, of Maidstone, as well as for most essential assistance in the mineralogy and the vegetable system, and for revising and correcting several other parts. It would be impossible to specify the authors from whom I have extracted my materials: I have inserted references as frequently as I could with convenience. In some instances the reference was neglected in the copying of my original notes; and in some, the facts were commonly known, and diffused through a multitude of authors.

*Chapel Street, Bloomsbury,*

*June 30th, 1796.*

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# C O N T E N T S.

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# BOOK I.

## OF THE GENERAL PROPERTIES OF MATTER.

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### CHAP. I.

#### OF MATTER IN GENERAL.

*Explanation of Terms.—Whether all Matter is radically the same.  
—General Properties of Matter.—Quantity of Matter in the  
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**T**HE word MATTER (*materia*, which some lexicographers have derived from *mater*, a mother) denotes, in its primitive sense, that unexplained something, from which all other things are formed.

The term *body* is sometimes confounded with that of matter; but they are essentially different: Body (*bodize*) is of Saxon origin. It is explained by the Latin words *statura*, *pectus*, *truncus*; and signified the *person* or *form* of a *man*, or other *creature*: whence it is plain that it ought to be confined to express a substance possessing form or figure.

*Substance*, both in its etymology and application, approaches nearer to the meaning of the former of these terms. It is well known to be compounded from the Latin preposition *sub* (under), and the

verb *stare* (to stand.) It consequently implies that which *supports* or *stands under* the different forms and appearances which are presented to our senses. It is still, however, used in a distinct and more limited sense than matter. It is generally indeed used with the definite article, to signify a distinct or definite portion of matter; whereas *matter* in the abstract implies a more confused and general idea of solidity and extension, with little or no regard to figure, proportion, or quantity.

These words are of such common and frequent use in philosophy, that it appeared necessary to have a competent notion of their force and meaning, particularly in a chapter which professes to treat of the first of them: and I have generally found etymology a safer and easier mode of communicating knowledge than definition.

That the whole matter, of which this universe of things is composed, is essentially the same, and that the apparent differences which subsist in different bodies depend altogether on the particular distribution or disposition of the component particles, is an opinion which has been entertained by some philosophers of the highest reputation. The wonderful apparent transmutations which take place in the different processes and operations of nature do, it must be confessed, at first sight countenance this hypothesis. A plant will vegetate and become a solid substance in the purest water\*. The genera-

\* See the experiments of Mr. Boyle and Van Helmont, Book VIII. c. iii.

tion of stones in the earth, the various phenomena of petrifications, and a multitude of other facts, contribute greatly, on a fair consideration, to diminish the absurdity of the alchemists, who seem chiefly to have rested on this hypothesis (*viz.* that all matter was intrinsically the same) their hopes of converting the basest materials by the efforts of art into the most splendid and valuable of substances.

Mr. Boyle distilled the same water about two hundred times, and at the end of each distillation found a fresh deposit of earth. M. Margraff repeated the experiment with still greater caution. By means of two glass globes, which communicated with each other, he preserved the water while in the state of vapour from all contact with the air; and on repeated distillation, a quantity of earth of the calcareous \* kind was deposited at the conclusion of each process.

The extreme rarity and minuteness of the particles into which different substances may be resolved, imparts a still greater degree of probability to this hypothesis; and in general, the more any body can be divided, the simpler it appears in its component parts.

We must however be cautious of admitting opinions, which are not sanctioned by the direct test of experiment; and however plausible the opinion, the accurate observations of modern philosophy have suggested some objections to the homogeneity of mat-

\* Earth of lime.

4                    *No Transmutation of Principles.* [Book I.  
ter, which without further discoveries it will not be  
easy to silence.

Whatever phenomena may appear to indicate a transmutation of bodies, or a change of one substance into another, we have the utmost reason, by the latest and best experiments, to believe them merely the effect of different combinations. Thus the conversion of water and air into a solid substance, such as the body of a plant, is merely an apparent conversion, for that solid substance may, by an artificial process, be resolved again into water and air, without any real change in the principles or elementary particles of which those fluids are composed: and the formation of stones, and the phenomena of petrifications, are accounted for upon much easier principles than that of transmutation. On the other hand, the utmost efforts of chemistry have never been able to proceed farther in the analysis of bodies than to reduce them to a few principles, which appear essentially different from each other, and which have never yet been brought to a more simple form. Thus the matter of fire, or light, appears totally different from that of all other bodies; thus the acid and alkaline principles can never be brought to exhibit the same properties; nor can even the different species of earths be converted into the substance of each other.

If hypothetical reasoning was to be admitted on this occasion, it would probably appear more agreeable to the analogy of nature, to suppose that different substances are formed from the different  
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rent combinations of a few simple principles in different proportions, than that the very opposite qualities of some of the rarest and most subtile fluids, should depend wholly on the different form or modification of the extremely minute particles which enter into their composition.

It is proper however to observe, that on this subject there has hitherto appeared no decisive experimental proof on either side. The imperfection of all human efforts, and perhaps of the human faculties themselves, have hitherto confined our investigations to the properties of a few substances, the simplest which chemical analysis has been able to obtain, and which for that reason are denominated ELEMENTS.

There are some properties which are accounted common to all matter, and which from their importance will require to be separately treated of: these are SOLIDITY, EXTENSION, and DIVISIBILITY, ATTRACTION, MOTION, and REST.

The quantity of matter which is contained in the whole universe may probably be much less than common observation would lead us to suppose. The sublime mathematics of Newton dictated the astonishing proposition: “ that the whole globe of earth, nay that all the known-bodies in the universe may, as far as we know, be compounded of no greater a portion of solid matter than might be reduced into a globe of one inch only in diameter, and even less\* !”

\* Pemberton's View of Sir I. Newton's Philosophy, 356.

## C H A P. II.

## OF ELEMENTS \*.

*Opinions of the Ancients.—New Arrangement.—Enumeration of simple Substances, according to the new Philosophy.—Aërial Substances.—Earths.—Metals.*

**W**HEN we take a general survey of nature, we find that notwithstanding the apparent variety of creatures, with which the universe abounds, every natural body which has hitherto come within the limits of our inspection may be reduced into a few distinct kinds of matter: and though we probably have not as yet discovered the ultimate and most subtle principles of which bodies are compounded; yet we appear to be justified in calling the most simple substances which we have been able to discover as entering into the composition of bodies by the name of ELEMENTS.

Aristotle, and after him most of the ancients, admitted four different elements, *fire, air, earth, and water*. It is evident, in the first place, that in this enumeration the salts are omitted, the existence of which can no more be doubted than that of any of the others. Secondly, it was found necessary in

\* From CLEO, or ELEO, to create.



the progress of science, not only to admit a *saline*, but a sulphureous or *inflammable* principle. I might add, that we are warranted by no experiments, which have as yet been made public, in supposing that there exists but one simple species of earth; and later experiments seem to determine that water as well as air is a compound substance \*.

It is, therefore, necessary to adopt a new arrangement, though it is more than probable that future discoveries may render it in some measure nugatory. Future discoveries may perhaps demonstrate that many, if not most, of the following substances will yet admit of subdivisions; or they may demonstrate that the constituent principles of bodies are still fewer. They may demonstrate that all earths have originally the same basis, and are only altered by different combinations with vital air or other substances; the alkaline salts may be in reality a species of earth, which also derives its distinguishing qualities from a union with some subtile matter in a certain proportion. These, however, are points on which we have at present obtained no experimental evidence, and which for that reason we are not authorized to affirm.

The most simple substances hitherto discovered may be resolved into,

\* I shall not perplex the reader with the exploded visions of chemists during the last two centuries, with their *phlegm* or watry principle, their *mercury* or active and spiritous principle, their *caput mortuum*, their *spiritus rector*, and a quantity of useless and almost unintelligible jargon.

1. Fire, heat, or caloric; including light and the electric fluid.
2. The base of pure, vital, or dephlogisticated air, the oxygen of the French chemists.
3. Hydrogen, or the base of inflammable air.
4. Azote, or the base of nitrous acid.
5. Sulphur, the base of vitriolic acid.
6. Phosphorus, the base of phosphoric acid.
7. Coal \* or Carbon, the base of fixable air.
8. The unknown radicals of the muriatic, fluoric, and boracic acids.
9. The fixed alkalis.
10. Earths.
11. Metals.

The different earths which are as yet known to philosophers are,

1. Calcareous, or earth of lime.
2. Silicious, or earth of flints.
3. Argillaceous, or clay.
4. Magnesia.
5. Barytes, or ponderous earth.

The metals again are subdivided into,

1. Arsenic.
2. Molibdena, or black lead.
3. Nickel.
4. Cobalt.

\* More properly charcoal, for our common pit-coal is a heterogeneous mass, containing much foreign matter, as may be seen book VI. c. 37. I have however employed the generic term *coal*, because charcoal, though much the purest of these bodies, is in this country considered not as a natural but a factitious substance.

5. Bismuth,

5. Bismuth.
6. Antimony.
7. Zinc.
8. Tungstein.
9. Manganese.
10. Tin.
11. Lead.
12. Iron.
13. Copper.
14. Mercury.
15. Silver.
16. Gold.
17. Platina.

Each of these may at present be considered as a distinct elementary substance, since they are found to be unchangeable or unconvertible into other substances, though they may be, and generally are, combined with others. This fact, was it not for the advantage of classification, and for some doubts which yet remain on the minds of philosophers concerning the essential difference of the earths, would oblige us to admit in nature, instead of eleven, at least thirty-three distinct, simple, and elementary substances.

## C H A P. III.

OF THE EXTENSION, SOLIDITY, AND  
DIVISIBILITY OF MATTER.

*Extension the only Quality essential to Matter.—Solidity, what.—Infinite Divisibility.—Animalculæ imperceptible to our Senses.—Extreme Rarity of Light,—Newtonian Paradox.*

**E**XTENSION is a property so obviously essential to whatever occupies space, that it is accounted the first and most indispensable attribute common to all matter. It is indeed the only property which we can positively say is essential to matter, since all the others that have been specified are to be understood with some limitation, and do not appear to be common to all bodies whatever.

We have no idea of *solidity*, but that which is furnished by the resistance which we find in a body to the entrance of any other body into the place it occupies till it has left it\*. This property of matter therefore necessarily includes neither impenetrability nor hardness; the amazing porosity of bodies militates against the one idea, and the almost infinite divisibility of matter against the other.

\* See Mr. Locke's *Ess. on Hum.* Under. B. ii. c. 4.

Indeed

**Chap. 3.] *Substances existing in the Pores of other Bodies.* 11**

Indeed nothing can be more inconsistent than to speak of the absolute solidity and impenetrability of the ultimate particles of matter, and afterwards to enlarge upon its infinite divisibility; both of these are facts which are totally undetermined by experiment or observation; and when we speak of the actual properties of matter, we ought, I apprehend, to confine ourselves to the testimony of our senses.

How improperly the idea of impenetrability is applied to any bodies which we are acquainted with, is evident from the astonishing ease and velocity with which the electric fluid passes through the densest bodies, and from the continual passage of light through a variety of substances, which afford to our senses the most perfect idea of solidity, through glass, and diamond and other precious stones: the focus of a burning mirror, which augments the density of the sun's rays upwards of three thousand times, may be received in glass or water without producing any effect: even substances of sensible bulk and solidity can exist within the pores of other bodies. Thus quicksilver exists within the pores of either silver or gold; in fact a mixture of mercury and silver is considerably heavier than an equal bulk of either of those metals. The common bell-metal is a mixture of copper and tin; and though the latter is specifically lighter than the former, yet bell-metal is considerably heavier than an equal bulk of copper itself; which is an evident proof that the particles of the one actually enter into, and  
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are deposited in the pores of the other. What is perhaps still more extraordinary, a definite quantity of salt may be added to a quantity of water without increasing its bulk, nay a small quantity of salt added to water will even cause it to contract.

The *divisibility* of matter is also received with limitation by those who contend for the existence of atoms or first principles of bodies; since, if their existence is admitted, there must necessarily be some parts or portions of matter indivisible, and consequently it cannot be admitted as a property inherent in all matter.

The human faculties are lost in the pursuit, and the human understanding in the contemplation of the actual divisibility of matter. The smallest animalcula which is brought within our notice by the microscope possesses organized parts, blood and other fluids necessary for the support of life, yet how infinitely removed are these from our inspection! Some idea, however, may be formed of the astonishing power of matter in this respect, from instances which are furnished by all the most common experiments of philosophy. A pound of even so gross a substance as cotton, may be spun into a thread upwards of one hundred miles in length\*; and Mr. Boyle speaks of a thread of silk 300 yards in length, which weighed no more than three grains and a half. This, however, is still surpassed by the amazing ductility of gold; sixteen ounces of which would

\* Repository, vol. ii. p. 52.

completely gild a wire sufficient to circumscribe the whole globe of the earth, though that quantity of the metal might be contained in a cube of not more than an inch and a quarter in diameter. The metallic particles are yet more minutely divided in the acid solutions. A small piece of the salt of silver, which is silver already divided and united to the nitrous acid, not larger than a common pin's head, will tinge a quart of water of a milky colour; and even the hundredth part of a grain of copper will impart a sensible blue to a pint of the same fluid.

It is well known that camphor, musk, and other odoriferous substances will emit particles that shall powerfully affect the organs of scent, and shall communicate their peculiar fragrance to the surrounding air for a considerable space of time, without any perceptible decrease of weight. The extreme rarity of the elastic fluids is a further proof of the divisibility of matter. Gunpowder, when exploded, expands to 244 times its bulk when in a solid state; and water in the state of vapour occupies a space 1800 times greater than in its natural fluid form\*. A par-

\* This fact may at any time be proved by an easy experiment. Take a common flask, and let it be exactly weighed; fill it with water, and then let it be weighed again—after the water is emptied, there will necessarily be a little moisture adhering to the sides; put the flask before a fire to evaporate the moisture, and when the whole of the water disappears, close the flask, and weigh it again, and you will then have the weight, and consequently the bulk of vapour, compared with that of water.

title of light has been estimated, on apparently a well conducted calculation, at  $\frac{1}{30,831,230,128,000}$  of a grain\*.

We shall indeed cease to wonder at such a calculation, when we consider that by means of this fluid the unparalleled wonders of the microscopic world are made cognizable to our senses. The scarf-skin of the human body is said to be composed of minute scales resembling those of fishes, *two hundred* of which may be covered by a grain of sand; under these scales there lie concealed a number of pores, or excretory ducts, through which the perspirable matter is supposed to issue, and *one hundred and twenty* of such pores in a direct line extend to only one tenth of an inch. If such therefore is the organization of the human body, what shall we think of the organized parts of those animals which are themselves *one thousand times* too small to affect the human eye without the aid of art? Animalculæ, however, have been discovered nearly one hundred times smaller than these, many thousands of which may dance upon the point of a fine needle: indeed Lewenhoeck calculates that one thousand million of such animalculæ as are discovered in common water would not equal in magnitude a grain of common sand. When therefore we consider that such animalculæ are possessed of organized parts; a heart, stomach, bowels, muscles, tendons, nerves, glands, &c. we seem to

\* Boudoin on Light. Memoirs of the American Acad. Vol. I. p. 198.



approach in idea the infinite divisibility of matter \*.

It is, on the other hand, next to an absolute certainty, that the particles of the hardest and most compact bodies are not in actual contact with each other, since all such bodies are known to contract with cold; which could not be the case, if their parts were already as close as they could be to each other.

It would be foreign to the design of this work to enter into those calculations and demonstrations by which mathematicians have attempted to prove how matter may be divided to infinity. Let it suffice to say, that on the principles which have been advanced in the course of this chapter, the sagacity of Newton has demonstrated, that the least portion of matter may be wrought into a body of any assigned dimensions, how great soever, and yet the pores of that body be none of them greater than any the smallest magnitude proposed at pleasure; notwithstanding that the parts of the body shall so approximate, that the body itself shall be hard and solid. His manner of demonstration is this—suppose the body to be compounded of particles of such figures, that when laid together the pores found between them shall be equal in size to the particles themselves; how this may be effected, and yet the body

\* If the reader wishes to satisfy himself concerning the nature and animal functions of a variety of these wonderful existences, I must refer him to my late much valued friend Mr. Adams's excellent *Treatise on the Microscope*.

remain

remain solid, is not difficult to understand; and the pores of such a body may be made of any proposed degree of smallness. But the solid matter of a body so framed will take up only half the space occupied by the body; and if each constituent particle is composed of other smaller particles, according to the same rule the solid parts of such a body will be but a fourth part of its bulk; if every one of these lesser particles again are compounded in the same manner, the solid parts of the whole body will be but one eighth of its bulk; and thus by continuing the composition, the solid parts of the body may be made to bear as small a proportion to the magnitude of the whole body, as shall be desired, notwithstanding the body shall, by the contiguity of its parts, be capable of being in any degree solid \*.—When these facts are considered, the hypothesis of the same incomparable philosopher, concerning the small quantity of solid matter contained in the universe, as noticed in a preceding chapter, appears less incredible.

\* Pemberton's View, 355.

## C H A P. III.

## OF ATTRACTION AND REPULSION.

*Five Kinds of Attraction—Cohesion—Combination—Crystallization explained—Gravitation—Specific Gravity, what—Magnetic and electrical Attraction—Repulsion.*

**F**IVE different kinds of attraction have been enumerated by modern philosophers. 1. The attraction of cohesion; 2. Of combination, or, as it is called by chemists, elective attraction; 3. Gravity; 4. The magnetic attraction; and, 5. The attraction of electricity. Whether the same principle acts in all these cases, or whether each of these effects depends upon a distinct cause, human sagacity has not been able to discover; nor is there any instance in which the principle of attraction seems to approach to the nature of a general law, except in that of gravity; and yet even this is not without an exception; since by every experiment that we have hitherto been able to make, there is no reason to believe that the element of fire, or heat, is subject to the common laws of gravitation. Unless, therefore, it could be proved that the principle of attraction is the same in all these cases that have been enumerated, we, perhaps, are scarcely correct in considering it as a general property of matter; and even

supposing the cause to be the same, it may, after all, belong rather to some particular species of matter, which acts upon or impels all other bodies, than to matter in general.

I. The attraction of COHESION may be observed in almost all the most common operations of nature, and is exemplified by a variety of easy experiments. Two leaden balls, having each a smooth flat surface, if strongly compressed together, will cohere almost as strongly as if united by fusion; and even two plates of glass, if the surfaces are even and dry, will require some force to separate them \*. By the same law of nature, the particles of even fluid bodies, in which the attraction is necessarily weaker than in solid substances, indicate a disposition to unite.

The drops of dew that appear in the morning on the leaves of plants, assume a globular form, from the mutual attraction between the particles of water. Small portions of quicksilver, when brought near to each other, will run together, and assume the same globular appearance. Also, by the same law, a vessel may be filled with water, mercury, or any other fluid, above the brim, and the fluid will be observed to rise in a convex form.

To this principle we may very properly refer what is usually termed *capillary* attraction. Thus, if a fluid is contained in a vessel not full to the brim,

\* See the ingenious Dr. Enfield's Institutes of Natural Philosophy.

it will always be attracted to the edges of the vessel, and will assume a concave form. Thus, also, if two plates of glass, at a small distance from each other, are immersed perpendicularly in water, the fluid will rise above its level between the two plates, and the height to which it rises will bear a certain proportion to the distance of the plates. A capillary tube is a tube with an exceedingly small bore, and by the same law which raises the water between the plates of glass, a fluid will rise to a considerable height in one of these tubes. Both these experiments will answer equally well in the vacuum of an air pump, which proves that the effect is not owing to the pressure of the air. In the same manner, also, by the same law, fluids will ascend in the cavity of a sponge, in the interstices of linen cloth, or any porous body.

II. The attraction of COMBINATION, or chemical or elective attraction, is in many respects analogous to the attraction of cohesion. Like the latter, it seems to depend on the minute particles of bodies being brought nearly into contact with each other; and indeed so nearly alike are the effects of these two species of attraction, that if they are different in principle, it is difficult to say which is the most essential to the cohesion and solidity of bodies \*.

Chemical

\* The two species of attraction are well defined by Bergman; that which he calls the attraction of aggregation, I class under that of cohesion; that which he calls composition, I call combination. When an increase of mass only takes place,

Chemical attraction may probably be no other than the attraction of cohesion acting in a free and unre-sisting medium, since its only distinguishing characteristic is the disposition which bodies in solution indicate to unite with certain substances in preference to others: To make this clear by an experiment—If a quantity of silver is added to a quantity of aqua fortis, the cohesion of the particles of the silver will be destroyed, and they will unite forcibly with those of the aqua fortis. The fluid will, however, remain perfectly clear, the particles being so extremely minute, that the rays of light will suffer no interruption in passing through them. If, however, to this 'solution' of silver a quantity of mercury or quicksilver is added, the aqua fortis will be attracted by the mercury, and the silver will be precipitated, or thrown to the bottom of the vessel in which the fluid is contained; if, again, copper is added, it will assume the place of the quicksilver; and if to this solution of copper a bright piece of

the nature of the body remaining still the same, this effect is denominated the *attraction of aggregation*. But heterogeneous substances, when mixed together, and left to themselves to form combinations, are influenced by difference of quality rather than of quantity. This we call *attraction of composition*, and when it is exerted in forming a mere union of two or more substances, it receives the name of *attraction of solution* or *fusion*, according as it is effected either in the moist or dry way. When it takes place between three respectively, to the exclusion of one, it is said to be a *single elective attraction*, and when between two compounds, a *double*, &c." Berg. on Elec. Attr. i.

iron (for rust would exclude the acid from coming in contact with the metal) is introduced, the acid will immediately quit the copper and seize upon the iron, a quantity of which being dissolved in the fluid, the copper will be deposited in its place on the surface of the bar of iron \*. The iron may afterwards

\* ‘ This experiment explains to us, in a very satisfactory manner, the nature of that *transmutation of iron into copper*, which travellers have been so much surpris’d at. Agricola speaks of waters in the neighbourhood of *Newsol*, in *Hungary*, which had the property of transmuting the iron which was put into them into copper †. In the year 1673, our countryman, Dr. Brown, visited a famous copper mine at *Herrn-Grundt*, about seven English miles from *Newsol*; he informs us that he there saw two springs, called the old and new *ziment*, which turned iron into copper. The workmen shew’d him a curious cup made of this transmuted iron; it was gilt with gold, had a rich piece of silver ore fastened in the middle, and the following inscription engraven on the outside:

‘ *Eisen-ware ich, kupfer bin ich,*  
 ‘ *Silver trag ich, gold bedeckt mich.*  
 ‘ *Copper I am, but iron was of old,*  
 ‘ *Silver I carry, covered am with gold ‡.*

‘ It was even at that time, he says, contended by some, that there was no real transmutation of iron into copper, but that the *ziment* water, containing vitriol of copper, and meeting with the iron, deposited its copper; and it seems as if he would have acceded to this opinion, could he have told what became of the iron. It is now very well understood what becomes of the iron; it is taken up by the water, and remains suspended in it, in the place of the copper; so that this transmutation is

† Agric. Fos. L. ix. p. 247.

‡ Brown’s Travels, ed. 1687. p. 69.

afterwards be displaced by the addition of an alkali. This species of attraction is called combination, because the particles of two bodies by those means become so intimately united or combined, that they cannot be separated but by the addition of a third body, which has a greater attraction for one of the component bodies than they have for one another, and it is called elective attraction and affinity, from the superior tendency in substances to unite with certain bodies in preference of others. In all cases of elective attraction it is necessary, that at least one of the bodies should be in a fluid state.

It is evident that all solutions must be the effect of an elective attraction. By *solution* I mean the dispersion of the particles of a solid body in a fluid in so equal a manner, that the compound liquor shall be perfectly and permanently transparent. In this case, therefore, it is plain that the particles of the fluid must have a stronger attraction for the particles of the solid body than they have for one another. A solid body may indeed, by mere mechanical means, be minutely dispersed through a fluid, but the compound in this case will be opaque and muddy, and if suffered to remain at rest, a sediment will immediately be deposited. Thus, if chalk or clay is incorporated with water, they will impart to

nothing but a change of place; and as the copper is precipitated by the iron, so the iron might be precipitated by potash, or any other substance which has a greater affinity with the acid of vitriol than iron has.'

Watson's Chem. Ess. p. 234 to 236.

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it their peculiar colour, and the fluid will be rendered in some degree opaque; but if common salt, or blue or green vitriol is added to water, the fluid will still remain perfectly transparent, though tinged with the peculiar colour of the salt. The former, therefore, is termed a *mixture*, the latter a *solution*. When a fluid has received so much of any solid body that it will not dissolve a particle more, it is said to be *saturated*.

The marks of chemical combination in bodies have been accurately defined by a correct and ingenious philosopher. The first is a *specific gravity exceeding that of the heaviest ingredients of the compound*. Though he properly observes, it does not necessarily follow, that where such density is wanting a chemical union does not exist; since the peculiar structure of the compound, which does not admit water into its vacuities, may prevent this property from being remarked; or a quantity of water may enter into a composition naturally heavier than water, and yet cannot be always made sensible.

Secondly, Transparency is always a mark of chemical combination. Such union, however, is also sometimes consistent with opacity, as that effect may sometimes arise from a mere mechanical arrangement of parts, from the interposition of some matter not properly combined, or from too great thickness.

Thirdly, *Crystallization* proves that the parts have been very minutely divided, and in general combined with the menstruum (or fluid in which

the bodies have been dissolved). Other substances, however, may sometimes intrude themselves into the crystallized bodies; though not chemically combined with them.

Fourthly, A difficulty of dissolving the compound body in the menstruum, or fluid, which is a proper solvent for one or both of the component substances \*.

It may be proper, before the conclusion of this section, to add a few words concerning one of the most curious effects of the attraction of combination, namely, *crystallization*. The word crystal is derived from *cryos* (frost), and *stellô* (to contract); it was originally confined to a particular diaphanous stone resembling clear ice, and was probably afterwards extended to all bodies which were transparent, and had their particles disposed in a regular manner, particularly the different species of salts. It is now expressive of that regular order or disposition, in which the particles of inert bodies arrange themselves on passing from a fluid to a solid state. This disposition of the particles is, however, by no means the same in all substances, but varies almost infinitely in different bodies. Thus common salt crystallizes into a cubic form, salt-petre into that of oblong pillars with six sides, cubic nitre into the rhomboidal form, vitriolated tartar and Glauber's salt into a mass of four or six sides. Each species of salt preserves its peculiar form however frequently the process of

\* Kirwan's Mineralogy.

dissolving it is repeated, and equally in the smallest masses which the microscope renders visible, and in the largest which art or nature have been able to produce \*.

• • If what has been said relative to crystallization be not perfectly intelligible to the reader, I would advise him to make the following easy experiment, which will give him a better notion of the matter than a thousand words. 'Into a basin full of boiling water, put as much saltpetre as the water will take up; if the saltpetre was purified, the transparency of the water will not be injured, it will still appear to be a homogeneous fluid: when the water will take up no more saltpetre, then he may conclude that it is saturated: let it stand without being stirred, till it grows cold. As it cools, a great many crystals, all of the same shape, may be seen shooting out from the sides and bottom of the basin, and increasing in size till the solution becomes quite cold. When no more crystals can be formed by that degree of cold which prevails in the apartment where the experiment is made, pour the liquor from the solid crystals; this liquor is still saturated with saltpetre; and in order to make it part with more of its saltpetre, some of the water which keeps it dissolved must be evaporated: upon the taking away a part of the water, a correspondent part of the saltpetre loses the power by which it is suspended, and ought, upon that presumption, instantly to fall to the bottom: yet it must be remembered, that the water from its increased heat during the evaporation, is able to support more saltpetre than if it was cold; and therefore the saltpetre will not begin to crystallize, notwithstanding the loss of part of its menstruum, till the remainder begins to cool. By repetition of this process of evaporation and crystallization, we may obtain all the saltpetre which was at first dissolved, as no portion of it can be evaporated with that degree of heat which is used in evaporating the water.'

Watson's Chem. Ess. p. 90 to 92.

It

It would perhaps be no rash assertion to say, that the whole mineral kingdom appears in a crystallized state; and this adds greatly to the probability that chemical combination or affinity is the great principle which has acted in the formation of all bodies. The causes of this peculiar distribution of parts are not to be demonstrated, and on so abstruse a subject, all that we are able to perform is to produce some probable conjectures.

The old and fanciful chemists and alchemists, who remarked the curious figures which saline substances assumed during their crystallization, imagined that the salts still retained the vegetative powers of the plants from which they were produced, and even thought they could observe the form of the plant in the crystallized masses. Later philosophers have ascribed to the primary parts of bodies a certain property which they call *polarity* (as analogous to that property of the *magnetic needle*) and which disposes them to shoot out in certain directions \*. A more probable opinion appears to be, that the minute particles of each crystallizing body are of such a form that the sides, which approach in contact, dispose them in a particular direction.

From this regular arrangement of the parts it results that homogeneous bodies possess always an equal density in all their parts; and in most cases, if nature is interrupted in the process, the concrete

\* Jones's Physiolog. Disquis. 22.

will be imperfectly formed. So nice and critical is the arrangement of the parts in sonorous bodies, that it is said the smallest vibration of the air occurring during the operation of casting a bell, or rather while the metal is settling in the mould, even the barking of a dog, will injure the tone \*.

III. The attraction of GRAVITATION materially differs from the two preceding species of attraction, since it requires neither the particles of the bodies, nor the bodies themselves, to be brought into immediate contact, but acts at considerable distances, and in this respect it is analogous to the attraction of magnetism and electricity.

The most obvious effect of gravitation is the general tendency of bodies to the surface, or perhaps to the center of the earth. It appears to be one of the great laws of gravitation, that the attraction of bodies is in proportion to the quantity of matter they contain. The earth, therefore, being such an immense aggregate of matter, is supposed to destroy the effect of this attraction between smaller bodies, by forcibly compelling them to itself. The attraction of mountains, however, upon the balls of pendulums has been found, by repeated observations, to be very considerable †.

The efficient cause of this species of attraction is as much a secret as all the other great principles of nature. Some philosophers have supposed gravity to be one of the inherent properties of matter;

\* Jones's *Physiol. Disq.* 22.

† Nicholson's *Introd. to Nat. Phil.* V. i. p. 26.

others have ascribed it to the agency of a subtle fluid; while others, with more modesty, and probably with more truth, have had recourse to the immediate agency and interposition of the divine power.

We are generally on sure ground when we describe effects. Ignorant as we necessarily are of the causes or instruments by which the supreme governor of the universe effects his purposes, an attentive observation will commonly furnish us with the obvious mode in which they generally take place. What philosophers term the laws of nature, are no other than the modes or forms in which her operations are usually effected; and this is precisely the case with what are called the laws or properties of gravitation.

First, It appears that the gravitating force being proportioned always to the quantity of matter, all bodies gravitate from equal distances with equal velocity, except prevented or impeded by some resisting medium. Thus, though a guinea and a feather will not fall to the ground with equal velocity in the open air, because of the resistance of that fluid; yet if the air by any means is removed, as in the vacuum of an air pump, they appear to fall at the very same instant of time: for though the guinea contains considerably more of solid matter than the feather, and consequently requires a more considerable force to put it in motion, yet it appears that the attractive power being proportioned to the quantity of matter, its velocity is equal to that  
of

of a body which requires less force to put it in motion.

Secondly, The attractive force of bodies is reciprocally as the squares of the distances. Thus, if a body is of the weight of one hundred pounds at the distance of ten diameters of the earth, at half that distance it would have four times that weight, or the force of gravity would be exerted upon it in a quadruple ratio, and so in proportion as it approaches the body of the earth.

It would perhaps have been more correct to have spoken of what is commonly called *specific gravity* in treating of the densities or porosity of bodies, but the reason why it was omitted on that occasion will presently be apparent. The truth is, we have no mode of determining the density of bodies, but by the first of these laws of gravitation, which have just been noticed. For since the force of attraction which nature exerts upon all bodies is in proportion to the quantity of matter which they contain, it follows of course, that if, of two bodies equal in bulk, the one is heavier than the other, that body is possessed of greater density, or contains more matter in the same compass.

The *specific gravity* is therefore the very same thing with the *density* of bodies, and has relation to the quantity of solid matter which different bodies contain in the same bulk. It is also called relative or comparative gravity, because we judge of it by comparing one body with another. If bodies are equal in bulk, it is evident their specific gravities may

may be easily determined by a common balance, and hence fluids, or any bodies that may be easily reduced to the same bulk or form may easily be weighed and compared. By weighing accurately a determinate quantity of any fluid, an ounce for instance, in a phial, and marking precisely the space which it occupies in the phial, the weight of the same quantity of any other fluid may easily be had and compared with the former.

The specific gravity of bodies which are not, nor can easily be reduced to an equal bulk, is not to be obtained by any method equally obvious to unphilosophical persons. A method, however, has been invented for determining the specific gravities of solid bodies, whatever their figure or dimensions. As it is an obvious principle, that every body when immersed in a fluid must displace a quantity of the fluid equal to its own bulk, and the resistance which it meets with from the fluid will be found exactly equivalent to the weight of the fluid so displaced; hence if any fluid, as water for instance, is taken as the standard of comparison, it will be easy to determine the specific gravity of different solids by weighing them first accurately in air, and afterwards weighing them in water, and comparing their loss of weight in this latter fluid, which will be in exact proportion to the space which they occupy. To make this clear by an experiment; suppose it was necessary to determine the specific gravities of any two metals, lead and tin for instance, I take a certain quantity of the former, and weighing it carefully



fully in air, I find its weight amounts to thirty-four ounces; on weighing it again in water, I find it weighs but thirty-one ounces, that is, it has lost three ounces of its weight, or in other words, the same bulk of water would weigh three ounces; the specific gravity of lead is therefore to that of water as 34 to 3 or as  $11\frac{1}{3}$  to 1. On weighing a certain quantity of tin, I find again that it amounts to fifteen ounces, and on weighing it in water it appears that it has lost two ounces of its weight. The specific gravity of tin is therefore to that of water as 15 to 2, or as  $7\frac{1}{2}$  to 1, consequently the comparative gravities of the two metals are  $11\frac{1}{3}$  to  $7\frac{1}{2}$  \*.

In the common tables of specific gravities, the weight of water is estimated at 1, and that of other substances is exhibited in the same ratio. To determine therefore the specific gravity of any substance heavier than water, weigh any given quantity of that substance in air in a common balance, and afterwards weigh it in water, carefully noting its loss of weight; divide the whole absolute gravity, or weight in air of the substance, by its loss of weight in water, and you will have its specific gravity.

IV. The attraction of MAGNETISM only differs from that of gravity in its operations being limited to particular substances. The *magnet* is an ore of iron, and its property of attracting certain portions of that metal at moderate distances is well known. Like the attraction of gravitation, that of magnetism

\* Nicholson's Philosophy, V. ii. p. 11.

bears a proportion to the distance, and probably to the quantity of matter (I should say of magnetic matter) in the attracting bodies. But the properties of the magnet are so curious and important in nature that they well deserve a distinct chapter.

V. The attraction of **ELECTRICITY** is also analogous to that of gravity in the property of acting upon bodies at a certain distance; but it differs from it in its operation being confined to a particular state of those bodies, that is, when excited by friction. But this peculiar species of attraction will be more amply treated of in a succeeding part of the work.

There is a property supposed to be incidental to matter, which is opposite to this of attraction, and which is therefore denominated **REPULSION**. It is a maxim of the Newtonian philosophy, that where the sphere, or power of attraction, terminates, that of repulsion begins. In the instance which has been already adduced of the round drops of dew upon the leaves of plants it is supposed not only that there exists an attractive force between the particles of the fluid, but a repulsive force between them and the leaf on which they are suspended. That the drops are not in actual contact with the leaf is evident from their white or pearly appearance; for this appearance results from the copious reflection of white light from the flattened part of the surface contiguous to the plant; and it is well known that this effect could not take place, unless there was a real interval between the under surface of the drop

drop, and the contiguous surface of the plant\*. The fact is also evident from another circumstance; the drop is not found to have the smallest adhesion to the leaf, but rolls off in a compact body with the greatest ease, which it could not do if the fluid was in actual contact with the leaf; or if there subsisted any degree of attraction between them.

In the same manner needles or other light metallic bodies will swim on the surface of a fluid. Flies walk upon water, and oil obstinately refuses to mix with that and other fluids. Hence the feathers of water fowl, which are covered with a thin coating of subtile oil, actually repel the surrounding water.

This principle of repulsion has, however, been disputed by some late philosophers; and all these effects have been accounted for by them, by supposing, not that there exists a positive principle of repulsion in the water, the oil, &c. but that the attraction of the leaf, of the water, &c. for the contiguous bodies is not sufficient to destroy the attraction which the particles of homogeneous fluids possess for each other.

The repulsion of magnetism and electricity will be treated of in those parts of the work which are appropriated to these subjects.

\* Priestley's Optics, p. 454.

## C H A P. IV.

## OF MOTION AND REST.

*Newtonian Theory of Motion and Rest.—Vis inertia.—Laws of Motion.*

**T**HE doctrines and laws of motion have a more intimate connection with the mechanical philosophy, than with a work which is strictly and literally physiological. As accidental properties of matter, however, motion and rest could not be wholly omitted in an investigation of the general principles of natural philosophy; though it will not be necessary to enter minutely into the detail of those mechanical powers which depend upon what are usually termed the laws of motion or of nature.

An attentive and judicious observation of the usual course of nature enabled Sir Isaac Newton to reduce the general principles or laws of motion to the three following axioms. There appears little necessity to illustrate them by particular instances, since they are confirmed by constant and universal experience; and however the application of these principles to the motions of the heavenly bodies, or to those departments of nature which are out of the reach of our observation, may be contested, their truth

truth and utility, with respect at least to those bodies with which we are best acquainted and have the most intimate connexion, will scarcely admit of dispute.

I. All bodies are perfectly indifferent to motion and rest. In other words, a body, if once at rest, will naturally remain so, unless disturbed by some power acting upon it; and a body in motion will continue that motion in the same direction, and with the same velocity, unless stopped or impeded by some external cause\*.

The first part of this proposition is evident from every part of nature, since no part or portion of inanimate matter appears capable of giving itself any degree of motion. The latter part of the proposition, namely, that a body will continue its motion for ever, unless prevented by external force, it is not so easy to illustrate by experiment, since we are not able to produce any species of motion which is not in some degree counteracted by the force of gravitation, or by some resisting medium. The conclusion, however, appears to be fairly drawn, since the less the obstruction which is opposed to any body in motion, the longer the motion continues; thus a ball will continue longer in motion on a smooth than on an uneven surface, whence we may reasonably infer, that if all obstacles were completely removed, motion once communicated would never cease †.

\* Pemberton's View, p. 29.

† See Enfield's Instit. Philosophy, p. 11, 12.

This property of resistance in matter is termed, in technical language, its *vis inertiae*.

II. The alteration of the state of any body, whether from rest to motion, or from one degree of motion to another, is always proportional to the force which is impressed, and in the direction of that force.

By this law, the degree of force is supposed to be measured by the greatness of the body which it can move with a given velocity. Thus a power which could give to a certain body such a degree of celerity in its motion as to enable it to pass in one hour the length of one thousand yards, would give to another body, half as great as the former, twice the degree of velocity, and would enable it to pass in the same time the length of two thousand yards \*. Hence the quantity of motion is always estimated by the swiftness of the motion, and the quantity of matter which is moved. If A and B, bodies of equal size, move with equal velocity, their quantity of motion is equal; but if A contains twice as much solid matter as B, and moves equally swift, it possesses a double quantity of motion †.

It follows evidently from the same law, that if a new force is impressed upon a body in motion, in the direction in which it moves, its motion will always be increased proportionably to the accession of force, however frequently repeated.

\* Pemberton's View, p. 29, 36.

† Elements of Nat. Phil. by Mr. Locke, chap. i.

It follows also, and may be proved by a very easy experiment, that if a new force is impressed upon a body not in the direction in which it moves, but in an oblique direction, the body will take a direction neither exactly the same as that in which it was proceeding, nor yet in the direction of the new force which is impressed upon it, but a direction between both. On this is grounded the commonly received opinion concerning the motion of the heavenly bodies. The centrifugal force is that which is supposed to have been impressed upon them at their first formation, and which would carry them forward in a direct line; this is counteracted by the force of gravitation (or centripetal force) which always inclines them to that body round which they revolve; the consequence of these two forces acting in different directions is, that the bodies always move in a curve, or orbit, which is more or less elliptical as one of these forces happens to be predominant.

III. The third law is, that re-action is always equal to action \*. In plain terms, the resistance of a body at rest, which is acted or pressed upon, acts against a moving body with a certain degree of power, and produces the same effects as would have been produced by a certain degree of active force exerted in a direction contrary to that of the moving body. Hence it follows, that any one body acting upon another actually loses as much force as it communicates, as will be evident, if with a small

\* Pemberton's View, p. 31.

bullet suspended from a string we strike another bullet which is at rest, or from observing a ball in motion on a billiard-table strike another which is at rest on the table; in both which cases the striking body will lose half its quantity of motion, and that quantity of its motion which it loses will be communicated to the other body \*.

This law is an effect of the *vis inertiae* of matter, and is extended to all cases where there is a resisting body. When a load is drawn by a horse, the load re-acts against the motion of the horse, and the progression of the animal is as much impeded by the load, as the motion of the load is promoted by the efforts of the animal. The finger which presses against any solid body is pressed by that body; but in elastic substances the effect is most apparent,

\* Enfield's Institutes, p. 12, 13.



## C H A P. V.

## OF MAGNETISM.

*Of natural and artificial Magnets.—Magnetic Powers.—Attraction.—Repulsion.—Polarity.—Declination.—Dipping of the Magnetic Needle.—Communication of the Magnetic Power.*

**T**HE properties of the magnet are illustrative of so many principles and laws of nature, that though, perhaps, not strictly in order, I have determined to introduce the subject before the conclusion of this preliminary book; as some occasions may shortly occur, when a reference to this topic may probably be useful, if not absolutely necessary.

It is well known that every magnet is a ferruginous body, and that its attractive force is confined in a great measure to ferruginous substances. Magnets are of two kinds, natural and artificial. The natural magnet or loadstone \*, is a bog ore of iron; artificial magnets are formed either by being touched with a natural magnet, or by other different processes, which will presently be explained.

\* *Lead* (Sax.) or *leading* stone, probably from its being a guide to mariners.—*Adams on Mag.* p. 377.

The properly magnetic ores are calciform (resembling a calx or cinder) and are mostly of a dull brownish black \*. There are reddish magnets found in Arabia; but most of those in Europe resemble wrought iron in colour. Their hardness is just sufficient to afford sparks with a steel, and they are with difficulty attacked by a file. They differ considerably in specific gravity, and seem to contain several substances besides iron in their composition, such as argillaceous and siliceous earth. Mr. Kirwan is of opinion that sulphur enters into their substance, as the ore smells of it when heated red hot: probably, also, they may sometimes contain nickel, as that metal, when purified to a certain degree, acquires the properties of the magnet.

Natural magnets are found more or less in almost every iron-mine, of different shapes, and of different sizes. Some old writers mention magnets that would swim on water †; these were probably some light, spongy, volcanic substances, impregnated with iron. In Virginia there is a magnetic sand, which contains about one half iron. Those magnets which have the finest grain possess the magnetic virtue in the highest perfection, and retain it longer than any other ‡.

The great and well-known properties of the magnet are, 1st, its attractive power; 2dly, its po-

\* Kirwan's Min.—and Cavallo on Magnetism.

† They are in general about seven times heavier than water.

‡ Kirwan and Cavallo.

larity,

larity, or disposition to conform to the plane of the meridian; 3d, the property of dipping or inclining to the earth; and lastly, the power of communicating the magnetic virtues to other ferrugineous bodies.

I. Magnets attract clear iron more forcibly than any other ferrugineous body. The iron ores are attracted more or less forcibly, in proportion as they are impregnated with the metal, and in proportion as it exists in a metallic state. The force of the attraction between a magnet and iron will depend in a great measure on the weight and form of the iron; but art and observation have furnished us with no invariable rule in these respects.

One magnet attracts another magnet in contact, with less force than it attracts iron; but the attraction between them begins at a much greater distance than between the magnet and iron alone.

As iron is diffused in greater or less quantities through almost all the different bodies of which the universe is composed, it is easy to suppose that the natural bodies which are subject to the magnetic attraction are very numerous. The perfect metals, gold, silver, and platina, as well as lead and tin, are however total exceptions; though their calces are a little attracted. Animal and vegetable substances also, though they are known to contain small portions of iron, seldom exhibit any disposition to be attracted before combustion \*; though it is

\* Cav. on Mag.

asserted that most substances may be rendered magnetic in some degree by being exposed to the action of fire.

Iron is attracted with different degrees of force, according to the different modes in which it exists. It is, however, in no state quite insensible to the magnetic power, even in the purest calx, or in a state of solution. Soft iron is the most subject to a forcible attraction; steel is less so than iron, especially when hardened, and the calces of iron in different degrees\*.

Muschenbroek, by a series of experiments, endeavoured to ascertain the force with which the magnet attracts at different distances. He suspended a cylindrical magnet, 2 inches long and 16 drams in weight, to one scale of an accurate balance, and under it he placed a cylinder of iron of the same shape and bulk. The following is the force with which it attracted at different distances, estimated by the number of grains in the opposite scale.

At 6 inches 3 grains.

5 ————— 3  $\frac{1}{2}$ .

4 ————— 4  $\frac{1}{2}$ .

3 ————— 6.

2 ————— 9.

1 ————— 18.

In contact — 87.

This experiment would perhaps have been more intelligible, if it had been previously remarked that the attraction between the magnet and the iron

\* Cav. on Mag.

is always supposed to be mutual. If a magnet and a piece of iron are placed so as to float on the surface of water, the magnet will approach the iron, as well as the iron the magnet; or if either of them are kept steady, the other will approach towards it\*.

Of natural magnets the smaller possess a greater attractive power, in proportion to their size, than the larger. There have been natural magnets of not more than 20 or 30 grains in weight, which would lift a piece of iron forty or fifty times heavier than themselves; and mention is even made of one of about 3 grains, which lifted a weight of iron containing 746 grains, or 250 times its own weight†. What is yet more extraordinary, it not unfrequently happens, that a loadstone cut off from a large one will itself lift a greater weight than the stone from which it was cut off. This circumstance may reasonably be attributed to the heterogeneous nature of the large loadstone; for if we suppose that one part of it, viz. that which is cut off, contains a considerable portion of magnetic matter, and that the remainder is impure, of consequence, while they remain in an united state, the impure part will rather obstruct the action of the other‡.

The power of magnets is not at all times equally active; they will at one time attract at a much greater distance than at others. To what this variation is

\* Adams on Magnetism, p. 385.

† Cav. on Mag. p. 36.      ‡ ib. p. 37.

owing, is impossible to decide, while we remain so perfectly ignorant as we are of the causes of all the magnetic phenomena: probably it may depend upon the temperature of the stone, as the magnetic power is always diminished by heat.

There is in magnets a natural power of repulsion, as well as of attraction. Two magnetic bars, for instance, will attract each other if the two extremities or poles, which correspond in each, are brought within the sphere of attraction; but if the extremities which do not correspond are brought into contact, they will be mutually repelled\*. This circumstance will be better understood when the polarity of the magnet has been properly explained. The power of repulsion is supposed by some experimentalists to be weaker than that of attraction.

II. The second distinguishing property of the magnet, is what is termed its *polarity*. In plain terms, if a magnet is placed in such a situation that it shall have liberty to assume that direction which is most natural to it, for instance if it is made to float on water upon a piece of wood or cork, if suspended by a slender string, or supported by a pivot, as is the needle in the common mariner's compass, it will dispose itself longitudinally nearly in the plane of the meridian, that is one extremity towards the north pole of the earth, and the other towards the south. The two extremities which correspond to

\* Adams on Mag. p. 389.

the poles of the earth are called the poles of the magnet: and at these extremities the magnetic virtues seem to exist in their greatest force, as a magnet will support a much more considerable weight near the poles than at any other part \*.

This property in the magnet has proved the basis of an invention the most useful to navigation that human sagacity ever discovered; as before this infallible guide was enlisted in the service of the mariner, the most adventurous pilot did not presume to trust himself out of the sight of land; consequently commerce is much facilitated by the discovery, and shipwreck is a much less frequent calamity. It was not till the thirteenth century that this circumstance was known. Authors are generally agreed at present, that a Neapolitan, of the name of John de Giojá, if not the inventor of the mariner's compass, was at least the first who made use of it in conducting vessels in the Mediterranean †. Some ridiculous pretences have been made by the Chinese to the honour of this, as well as of other European inventions; but the fables of that barbarous people, as well as of their encomiasts, the jesuits and infidels, are little to be regarded ‡.

Both the properties of attraction and repulsion have an intimate connexion with this of polarity. Thus, it is uniformly found to be the case, that in two magnets an attractive force obtains between

\* Adams on Mag. p. 387.

† Cav. on Mag.

‡ See Mr. Adams's Essay, p. 409.

the opposite poles, and a repulsive force between the poles of the same denomination. If, for instance, the north pole of the one is brought near the north pole of the other, a mutual repulsion will take place; but if the south pole of the one is applied to the north pole of the other, they will be mutually attracted. And if, upon the same principles, a magnet is cut through the axis, the parts or segments of the stone, which before were united, will now repel and avoid each other\*. If two magnets of a spherical form are freely suspended, one will conform itself to the other, as to the poles of the earth. This influence of one magnet over another is termed the directive power, and this directive power acts at a greater distance than that of attraction. This may be proved by placing one magnet at the bottom of a scale, and holding the other at the same distance at which it acts in altering its direction: in this case no degree of attraction will be produced†. If a quantity of iron filings are gently dusted on a magnet, they will arrange themselves around it in a very whimsical manner: this effect is only to be accounted for from the directive power of the magnet, for the filings by contact with the magnet assume the magnetic virtue, that is, become each of them a small magnet, and arrange themselves according to the polarity of the original magnet‡.

\* Adams on Mag. p. 444.

† Cav. p. 98.

‡ ib.—Nicholson's Phil. ii. p. 296.

Neither



Neither the directive nor the attractive power of the magnet is diminished by the interposition of a foreign body. Steel filings scattered on a plate of metal, or of wood, or of any body not magnetic, will be affected by the motions of a magnet under the plate; and ferrugineous bodies are attracted with the same ease, and at the same distance, in the vacuum of an air-pump, as in the open air \*.

Natural magnets are frequently found to have more than two poles. That is, the poles of another magnet of the regular form will frequently be attracted by different parts of the surface. This circumstance depends on the form and heterogeneous nature of these irregular magnets: for a good loadstone is always of an uniform texture, and has only two poles, which lie in opposite points of the surface, in such a manner, that a line drawn from the one to the other would pass through the center of the magnet †. When a magnet has more than two poles of equal strength, the supernumerary poles may be so situated that the magnet will not, in the technical language, traverse; in other words, it will not, when suspended by a thread, &c. or when floating on water, assume the usual direction to the poles of the earth ‡.

The magnetic meridian seldom coincides with the real meridian, but generally is found to vary a few degrees from the true direction of north and south.

\* Enfield's Instit. p. 340.

† Cav. p. 40.

‡ ib. p. 43.

This is called the declination of the compass. The magnetic needle varies sometimes to the east, and sometimes to the west; and it varies not only in different places, but even in the same place at different times. The declination at London is not the same now as it was a few years ago\*. Nay, some

\* The following table shews the mean declination of the needle at different times in Paris and London.

Year.	Paris.	Year.	London.
1580	11 30 E.	1576	11 15 E.
1610	8 0 E.	1634	4 5 E.
1640	3 0 E.	1657	0 0.
1666	0 0.	1665	1 22 W.
1670	1 30 W.	1692	6 0 W.
1700	8 12 W.	1730	10 15 W.
1728	14 0 W.	1756	15 15 W.
1771	91 45 W.	1774	21 16 W.
		1776	21 47 W.

Near the equator, in long.  $40^{\circ}$  East, the highest variation, from the year 1700 to 1756, was  $17^{\circ} 15'$  West; and the least  $16^{\circ} 30'$  W. In lat.  $15^{\circ}$  N. and long.  $60^{\circ}$  W. the variation was constantly  $5^{\circ}$  E. In lat.  $10^{\circ}$  South, and long.  $60^{\circ}$  E. the variation decreased from  $17^{\circ}$  W. to  $7^{\circ} 15'$  W. In lat.  $10^{\circ}$  S. and long.  $5^{\circ}$  W. it increased from  $2^{\circ} 15'$  to  $12^{\circ} 45'$  W. In lat.  $15^{\circ}$  N. and long.  $20^{\circ}$  W. it increased from  $1^{\circ}$  degree W. to  $9^{\circ}$  W. In the Indian seas, the irregularities were greater, for in 1700, the west variations seem to have decreased regularly from long.  $50^{\circ}$  E. to long.  $100^{\circ}$  E. but in 1756 the variation decreased so fast, that there was east variation in long.  $80^{\circ}$ ,  $85^{\circ}$ , and  $90^{\circ}$  E. and yet, in long.  $95^{\circ}$  and  $100^{\circ}$  E. there was west variation.

In the year 1775, in lat.  $58^{\circ} 17'$  S. and long.  $348^{\circ} 16'$  E. it was  $0^{\circ} 16'$  W. In lat.  $2^{\circ} 24'$  N. and long.  $32^{\circ} 12'$  W. it was  $0^{\circ} 14' 45''$  W. In lat.  $50^{\circ} 6' 30''$  N. and long.  $4^{\circ} 0'$  W. it was  $19^{\circ} 28'$  W. Enfield's Inst. Phil.

very nice observations seem to determine that the declination varies at different times of the day \*.

The polarity of the magnet has been attempted to be accounted for, by supposing the earth a large loadstone, or at least that a mass of ferrugineous matter, equivalent to such a loadstone, is contained within the bowels of the earth, to which all smaller magnets must necessarily conform. Attempts have also been made to explain the variation or declination of the compass upon similar principles. If the mass of ferrugineous or magnetic matter which the earth contains is supposed to act upon all magnetic substances, and if this mass is almost constantly varying its position and composition by subterraneous fires, it is not very difficult to suppose, that the magnetic needle will be subject to considerable variations from these important movements †.

The magnetic centre is the point between the two poles, where the magnet possesses neither attraction nor repulsion. If, however, a part of a magnetic bar is broken off at either pole, the fragment will still be a complete magnet, having two poles and a centre, though it originally might belong to a part of the magnet which was altogether of a certain polarity ‡.

III. Magnets, while they attract other bodies, appear themselves to be subject to the attraction of the earth; for a magnet, or magnetic needle, when placed so as to be able to act according to its

\* Adams on Mag. p. 415, 416. † Nicholson's Phil.

‡ Cav. 218.

native impulse, inclines one of its poles a little to the earth, while the other is proportionably elevated: this is called the *dipping* of the needle, and the inclination or dipping is found to be different in different latitudes. Near the equator the needle assumes a position almost perfectly horizontal; in the northern hemisphere the south pole is depressed or attracted to the earth; and in the southern latitudes the north pole of the magnet suffers a similar depression.

This property of the magnet is accounted for upon the same principle as the former, namely, by supposing that the earth, from the quantity of ferrugineous matter which it contains, acts as an immense loadstone, which at its poles attracts those of every other magnet suspended above its surface. It has more than once been repeated, that magnets attract each other at the opposite poles. Thus, if a small magnet, or magnetic needle, is suspended by a thread above a larger magnet, while its poles are at equal distances from the poles of the larger magnet, it will remain in a horizontal position; but if it is removed either one way or the other, that is, if one pole of the smaller magnet is moved towards the contrary pole of the larger, it will be attracted towards the perpendicular. This is exactly illustrative of the dipping needle, which upon the equator remains in an equilibrium, but inclines to the perpendicular as it approaches to the poles of the earth; and what is still more agreeable to this theory is, that the dipping or inclination of the  
needle

needle is greatly increased as it approaches either pole.

IV. The magnetic virtue may be communicated to any ferrugineous body.

1st. By contact with a real magnet: and in this way artificial magnets are in general prepared. This property of imparting the magnetic powers is not, however, confined to the natural magnet, for artificial magnets are capable of communicating it to fresh ferrugineous bodies, and that without the least diminution of their own power \*: and the power may in this manner be communicated from one piece of iron to another to infinity. A weak magnet may also be rendered more powerful by the application of a stronger.

Soft iron acquires magnetism with more ease than hard iron or steel, but the virtue is not so permanent. Hard steel will retain it for many years without diminution.

To make artificial magnets of extraordinary power, some address is required. A single magnet cannot communicate a greater degree of power than itself possesses, but several magnets united will impart a power equal to their united force †. It will easily be imagined, that the power imparted will be in proportion to the approximation of the iron to

\* It is said indeed that the power of a magnet is increased rather than diminished by communication.—*Cav.*

† Hence it is evident, that artificial may be made much stronger than any natural magnets whatever.—*Adams on Mag.* 378.

the magnet. To acquire a very high degree of magnetism also, the iron ought to remain some time in contact with the magnet.

There are several curious phenomena which attend communicated magnetism. The nature of the magnetism communicated will frequently depend upon the length of the iron bar which is brought into contact with the magnet. If, for instance, the north pole of a magnet is applied to the extremity of a long bar of iron, that extremity will of course acquire a contrary virtue, and become a south pole; at a part of the bar, however, not very distant, there will be found a new north pole; at some distance again a south pole; and so alternately, till the power is totally lost; the number of these successive poles depending on the strength of the magnetism, and the length of the bar. If, however, the bar is of a moderate length, there will be only two regular poles\*.

The polarity of a bar of iron may be altered by gradually moving the pole of a magnet along its surface. Thus, if the north pole of a magnet is applied to that extremity of a magnetic bar of iron which is the south pole, and moved gradually along, the other (that is that which was the north) pole of the bar will in that case be converted into a south pole†.

If a piece of wire which has been rendered magnetic is twisted, its virtue will be strangely interrupted and confused. In some parts it will attract,

\* Cav. part i. c. 7.

† Ib.

Chap. 5.] *How Iron may acquire Magnetic Power.* 53

in others it will repel ; and even in some places one side of the wire appears to be attracted, and on the other side repelled, by the same pole of a loadstone \*. This and other phenomena seem to indicate, that much of the magnetic power depends upon the texture of the substance which retains it.

Every portion of iron is capable of retaining only a certain degree of the magnetic virtue. If a strong magnet is applied to a small piece of steel, the steel, while within the influence of the magnet, appears powerfully magnetic ; but if the magnet is removed, the power subsides to a certain degree, which may be termed the point of saturation †. A number of magnetic bars, however, may be joined together, so as to form an exceedingly strong compound magnet ‡.

2dly. Iron is rendered magnetic merely by being kept a considerable time in a situation perpendicular to the surface of the earth ; and in this hemisphere the lower extremity will be the north pole, and of consequence the contrary effect will take place in the southern hemisphere. This phenomenon also is explained from the magnetism of the earth, which communicates its power to ferruginous bodies, though by almost imperceptible degrees. Old iron bars in windows, &c. are frequently found to be strongly magnetic §.

\* Rees's Cylop. art. *Magnet* ; and Adams on Mag. 399.

† Cav. 92.

‡ Ib.

§ Lewenhook mentions an iron cross, which had acquired a very strong polarity.—*Adams*, 432.

## 54 *How Iron may acquire Magnetic Power.* [Book I.

The most advantageous situation of the bar is however not directly perpendicular, but rather in the direction of the dipping needle; and indeed the magnetic virtue which it acquires seems to be in proportion as it approaches that direction. Hard iron or steel acquires little or no magnetism from the earth, on account of its greater insensibility to the magnetic influence; but it is well known that iron hardens by exposure to the atmosphere; it has been said, therefore, that bars of soft iron, which have remained for a long time in a magnetic direction, have acquired as strong a power as good natural magnets\*.

A bar of iron made red hot, and left to cool, or quenched in water in the position of the dipping needle, acquires a degree of magnetism proportional to its nature, and the circumstances of its cooling†.

3dly. Magnetism may be imparted to a bar of iron, by placing it firm in the direction of the dipping needle, and rubbing it hard one way with a polished steel instrument‡.

4thly. Any violent percussion will impart polarity, and the other magnetic virtues, to a bar of iron in a vertical position. A few strokes of a hammer will produce this effect; and by hitting first one end of the bar, and then the other, the poles may be changed. If a long piece of wire is twisted several times backwards and forwards, and then broken off

\* Cav.

† Adams, and Cav.

‡ Nicholson's Phil. 292.



at the twisted part, the broken end will be magnetic \*.

5thly. Even hard iron tools, when heated by any brisk action, as hammering, filing, &c. acquire an impermanent magnetism, and, while warm, attract thin filings, or small portions of iron †. This fact, I am inclined to suspect, must depend in a great measure on the unequal texture of those tools: if we suppose them to be composed of hard and soft particles, the latter will easily acquire an impermanent magnetism.

6thly. Apparently all the three last-mentioned effects depend upon precisely the same cause; and, perhaps, we may add to these, the magnetism which is produced by electricity. If a bar is laid horizontally to the magnetic meridian, and subjected to the electric shock, whatever may be the direction in which the shock enters, that extremity which is pointed towards the north, will be the north pole; and if the bar stands perpendicular, it will follow the usual law of communicated magnetism, that is, in this hemisphere, the end which is next to the earth will be the north pole ‡. Lightning is the most powerful of all natural agents in producing immediate magnetism; it will, in an instant, render hardened steel strongly magnetic, and will invert the poles of the magnetic needle §.

One of the most singular properties of the magnet is, the increase of power which may be added to

\* Adams on Mag. 444. † Rees Cyclop. art. *Magnet.*

‡ Cav.

§ Adams on Mag. 398.

56 *How to increase the Power of Magnets.* [Book I.

it by gradually increasing the weight it sustains; and on the other hand, it will gradually, by disuse, lose much of its natural strength \*. If a magnet is hung up with a weight of iron, as much as it will for the present sustain, by adding gradually, suppose a few grains daily, it will at length acquire the power of attracting near double the weight which it would have attracted at first. It is probable, however, from what was formerly remarked, that this power has a limit.

If a piece of iron, somewhat more ponderous than a magnet will sustain, is applied to the pole of the magnet, it is plain that on removing the hand the iron must fall. But if another piece of iron is held at some little distance below the first, the magnet will be able to support it. The reason is, that both pieces of iron being rendered magnetic, the first piece is actually converted into an artificial magnet, by its contact with the original, and its virtue is increased by the second piece of iron, consequently it is rendered capable of a greater degree of attraction for the original magnet †. To make this perfectly clear, it is necessary to be observed, that a piece of iron, brought within a certain distance of a magnet, becomes itself possessed of all the magnetic properties, and that part of the iron which is nearest the magnet acquires a contrary polarity. Thus, if a magnetic chain is composed of several pieces of iron, each piece is in itself a complete magnet, and they

\* Cav. 25.

† Cav. 200.

mutually strengthen the magnetic virtue of each other\*, as all magnets in contact are known to do.

The magnetic virtue is DIMINISHED :

1st. By *disuse*: particularly if the magnet is laid amongst iron, or permitted to rust. Magnets will also be injured, unless they are kept together with the opposite poles corresponding, the ends being connected by pieces of iron; and they ought never to touch, except when in this position. The south pole should always be employed in this hemisphere to lift iron; and a strait magnet will be weakened, unless kept with its south pole to the north in the direction of the magnetic needle, or downwards in that of the dipping needle †.

2dly. *Heat weakens the power of a magnet*; and that high degree which is called by chemists a white heat, entirely destroys it ‡. On this principle Mr. Canton endeavoured to account for the daily variation of the compass; as supposing it to depend on the heating and cooling of the magnetic substances within the earth. This theory he illustrated by the following experiment:—About E. N. E. from a compass he placed a small magnet, exactly at such a distance, that the power of the magnet at the south pole was just sufficient to keep the north end of the needle to the N. E. point, or 45 degrees. He contrived to heat the magnet, by putting upon it a brass

\* See Cav. p. 30 and 203.

† Adams on Mag. 397, 443.

‡ Cav. 35.

58 *How the Magnetic Power is diminished.* [Book I.

vessel, into which he poured about two ounces of boiling water, and as the magnet gradually heated, he observed, during seven or eight minutes, that the needle moved about three-quarters of a degree westward, and became stationary at  $44\frac{1}{4}^{\circ}$ ; in nine minutes more it came back a quarter of a degree; but it was some hours before it gained its former situation, and stood at  $45^{\circ}$  \*.

3d. In general the same means which facilitate the communication of magnetism to ferrugineous bodies not magnetic, tend to deprive those which really are so of the magnetism they have acquired. Every kind of violent percussion weakens the power of a magnet; and a very strong magnet has been entirely deprived of its virtue by receiving several smart strokes with a hammer †. This effect appears to depend chiefly on the derangement of the particles in the magnetic bodies. Thus, if a dry glass tube is filled with iron filings, magnetism may be communicated to the tube by touching it with a loadstone, exactly as if it was an iron bar; but the least agitation which disturbs the situation of the filings will presently expel the magnetic virtue ‡.

4th. In the same manner the electric shock, which imparts the strongest virtue to iron not previously magnetic, will diminish, and even destroy, the power of a real magnet. Electricity will also sometimes invert the poles of a magnet §.

\* Adams on Mag. 417.    † Ib. 443.    ‡ Ib. 444.

§ Cav. part i. c, 7; and Adams on Mag. 446.

The phenomena of magnetism stand alone among the wonders of philosophy, unless we suppose the attraction of gravitation to be a species of general magnetism, which indifferently affects all the various bodies of which this universe is composed. Certain analogies have been traced, or rather imagined, between electricity and magnetism. Both powers are excited by friction; and the magnetic polarity has been compared to the two states of positive and negative electricity. The analogy is favoured also by the possibility of imparting the magnetic virtue to iron by the electric shock; and the Aurora Borealis, which is generally accounted an electrical phenomenon, is supposed to have some influence on the variation of the magnetic needle. These powers, nevertheless, I must avow, appear to me essentially different. The phenomena of electricity are not at all times exhibited by electrical bodies, but merely when those bodies are in a state of excitation. When the electrical virtue is imparted from one body to another, the body that imparts it loses proportionably of its own power, but the magnet rather increases than diminishes its strength by communication. The electric matter is visible; whereas the very existence of a magnetic fluid is justly questionable; besides that electricity, both in its nature and effects, bears so close an analogy to another apparently very different power in nature, that there can be no reason for referring it to one with which it appears to have a very slight, and, most probably, only a casual, agreement.

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The polarity of the magnet, as well as the dipping of the needle, are in all probability mere effects of its great property, attraction, since they appear to be fairly accounted for, from the strong and peculiar attraction which the magnet appears to have for the earth, or rather for that immense mass of ferrugineous matter which the earth contains. The attraction of the magnet is commonly supposed to depend upon the agency of a subtile fluid which circulates around it, enters the pores of the magnet itself, and of all the bodies which it attracts. I confess that the theories which are founded upon this hypothesis appear to me so deficient in the only proof that ought to be admitted in natural philosophy, I mean actual observation, and I am still inclined to account the cause of magnetism as one of the undiscovered principles of philosophy. I am not fond of indulging the imagination in its favourite propensity to create invisible agents in order for the fabrication of plausible theories, which some slight and casual experiment may shortly overturn. We appear to be equally ignorant of the nature of gravitation, and of the common attraction of cohesion and combination. It is a trite remark, that there are certain points at which the human faculties must stop in all our speculations. This would be a dangerous tenet, if it promoted indolence, or discouraged our ardour in the pursuit of natural knowledge by the only secure path, I mean that of experiment; but it is a salutary maxim when applied to the imagination, and when it only serves to restrain  
our

our ardour for fabricating systems, which have no other end but to remove for a moment the uneasy but useful sensation of doubt and curiosity.

I shall not therefore incumber my work with the detail of systems to which I do not feel inclined to assent; but for a clear, and, I think, correct, statement of the most plausible theories concerning the causes of magnetism, shall content myself with referring my reader to an author to whom I have many obligations, and whose loss, as a friend, I can never sufficiently lament; and shall direct him to consult the late Mr. Adams's ingenious Essay on this subject \*.

\* Printed in the same volume with his Essay on Electricity. In the same Essay the reader, who wishes to entertain himself with the practical and experimental part of magnetism, will find proper and easy directions.

## B O O K II.

## OF THE NATURE OF FIRE.

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C H A P. I.HISTORY OF THE DISCOVERIES  
RELATIVE TO FIRE AND HEAT.

*Opinions of the Ancients.—Of Bacon, Boyle, and Newton.—Of  
Homburg, Sgravesend, and Lemery.—Invention of the Thermo-  
meter.—Opinion of Boerhaave.—Great Discovery of Dr. Black.*

**S**O wonderful is the nature, so extensive is the action, and so eminent is the power of fire, that by one of the greatest nations of antiquity\* it was adored, as the embodied presence of the supreme God: and even in countries where the adoration was less palpable and direct, something mysterious was always attributed to this subtle and astonishing element; and the rites and mysteries of fire were celebrated in temples and in groves, from the shores of the Hellespont to the banks of the Tiber.

An opinion seems to have been prevalent among the early philosophers of Greece, that fire is the

\* The Persians.—See Herod. Lib. III. c. 18.



only elementary and homogenial principle in nature, and that from its different modifications all this variety of different bodies is produced \*. This idea is ridiculed by Lucretius, who adopts the system of Epicurus: and indeed the Epicureans, as well as the Peripatetics, seem to have considered fire as a distinct elementary substance, capable of combining with the other elements, but by no means the matter from which they are originally generated.

The history of error can afford but little instruction, otherwise volumes might be filled with the fantastical opinions which have been from time to time entertained concerning the element of fire. On the revival of letters and philosophy, our illustrious Bacon, in a treatise expressly written upon the subject †, endeavours to prove, that heat is no other than an intestine motion or vibration in the parts of bodies; and he was followed by most of the philosophers of this kingdom during the last century. The opinion of Bacon is supported by a variety of facts, which are adduced by Mr. Boyle in a dissertation on the *mechanical origin of heat and cold* ‡; nor does the system appear repugnant to the sentiments of Newton; though he speaks of it with that diffidence which is always observable in his writings,

\* Lucret. lib. i. 636.

† De forma Calidi.

‡ Mr. Boyle, however, though thus apparently deceived with respect to the cause of heat, in another essay reasons justly with respect to its effects. He considers ice not as the preternatural state of water, but water as ice preternaturally thawed by heat.

*Boyle on the nat. and preternat. State of Bodies.*  
luctance

**64** *Opinions of Homberg, Sgravesend, &c.* [Book II.

when treating of facts not absolutely demonstrated by experiments of his own \*.

Notwithstanding the reputation of the English philosophy, this theory was received with great reluctance abroad. The celebrated Homberg, Sgravesend, and Lemery the younger, assert, that fire is a distinct substance or body, which enters into combination with all other bodies, pervades all bodies, and may be again expelled from them by violent motion or compression, though the fire is certainly not generated by such motion †.

One of these philosophers (M. Lemery) indeed carried his system much further, and made a very near approach to the received doctrines of the present day. He asserted, that fire is not only contained in those bodies which are inflammable, but even in water itself. Ice he affirmed to be the natural state of water; and he added, that the fluidity of that substance is a real fusion, like that of metals exposed to the fire, only differing as to the quantity of heat necessary to preserve it in fusion ‡.

About the commencement of the last century instruments were first contrived for measuring the heat of bodies by the degree of expansion; and this invention seemed to give some colour to the hypothesis of the German philosophers, since it is not very clear how a mere increase of motion can in-

\* Optics, 318, 349.

† The reasons in support of each of these theories will be considered in the following chapter.

‡ Mem. de l'Acad. Roy. 1709.

crease the extent of bodies. It was long observed, that all bodies are expanded by an increase of heat; and it was evident that fluid matters were affected more than solids. The first substance therefore that was employed, was the very expansible and elastic fluid *air*; a quantity of this fluid was inclosed within a small tube, with a small drop of oil, or some coloured liquor, at the top, which served to shew the expansion which the inclosed air underwent from the increase of temperature. As this thermometer, however, was open at the top, it was also found to be affected by the external air; tubes hermetically sealed were therefore presently substituted, and the coloured liquors themselves were found to be sufficiently expansible to mark the degrees of heat. Spirit of wine was employed by the Florentine academicians, and oil was afterwards made use of by Sir Isaac Newton; who constituted the points at which water freezes, and that at which the same fluid boils or assumes the form of vapour, as extreme points of his scale of heat. These thermometers were however superseded, at least in England and Germany, by the invention of Olaus Roemer, afterwards improved by Fahrenheit, who substituted mercury in the place of the other fluids which had previously been employed in the construction of thermometers.

The sagacious and learned Boerhaave, both by his own experiments and by his attention to those of others, contributed greatly to the elucidation of the doctrine of heat and fire. He was a strenuous assertor of the existence of fire as a distinct elemen-

tary substance. Expansion or rarefaction he considers as the uniform sign or criterion of its existence in other bodies. The production of fire from the attrition of two hard bodies, as a flint and steel, or two pieces of hard wood, &c. he accounts for, by supposing that the parts of these bodies will every moment be violently compressed, which will excite in them, by their re-action, a vibratory motion, and this will necessarily excite and expel the fire which existed latent in their pores; and as fire is capable of being produced in this manner by the violent attrition or motion of all bodies, he infers that it is present through every part of nature; yet, since it is expelled by the attrition or vibrations of the particles, he thinks it is clear that it does not penetrate the integrant or elementary particles of bodies, but exists only in their pores or interstices. As fire is supposed to exist in all bodies, he proves its existence in air and water; and agrees in opinion with the younger Lemery, that ice is the natural state of water, and that it is kept in a fluid state by a quantity of fire which it absorbs.

There is a period when the minds of men are prepared for the reception, as well as for the prosecution, of great discoveries in science. The hints, for they are little more, which had been afforded by these philosophers, appear to have made little impression; and the nature of heat, fire, and fluidity seems to have been involved in obscurity and contradiction, till the genius and industry of Dr. Black, of Edinburgh, developed a system, which explains  
satisfactorily

satisfactorily a variety of the most curious and difficult phenomena in nature. By a number of nice observations, he was enabled to determine that absolute heat or fire was absorbed by all bodies whatever, and that it was absorbed in greater quantities by fluid than by solid substances; heat therefore he considered as the cause of fluidity. He found further, that bodies in passing from a solid to a fluid state absorb a quantity of heat without increasing their temperature or sensible heat, as manifested by the thermometer. Thus, if water with a quantity of solid ice is set over the fire, the temperature of the water will not be increased, but will continue at the heat of 32 degrees, the freezing point, till every particle of the ice is dissolved. The reason is, that fire being absolutely necessary to impart fluidity to any body, in proportion as the ice becomes fluid the superfluous fire is absorbed. In the same manner, when the fluid is converted into vapour, a quantity of absolute heat or fire is absorbed without any increase of temperature above the boiling or vapourific point. This discovery Dr. Black was led to by heating water in a close furnace a considerable degree above the boiling point; when on opening the vessel in which the water was confined, he found that a small quantity of the fluid burst out suddenly in the form of vapour, and the temperature both of the vapour and of the remaining water immediately sunk to the boiling point. It was evident therefore that the superfluous heat was absorbed by the vapour, and as the quantity of water which was lost by the

process was not great, it followed that a considerable quantity of the matter of heat or fire is necessary to keep water in a state of vapour. When any quantity of heat is expelled from a body, in such a manner as to affect our touch, it is termed, according to Dr. Black's theory, *sensible* heat; and when it is absorbed by any body, and exists in combination with that body, either in a fluid or vapourific state, it is termed *latent* heat. It is also evident from what has been stated that the opinion of these later philosophers is, that heat or fire, which has also been called *igneous fluid*, *matter of heat*, and lately by the French chemists *caloric*, is a distinct substance or fluid, which has an attraction for all other substances; that it pervades most bodies; that it is the only permanent fluid in nature, and the cause of fluidity in all other bodies. That not only common fluids, such as water, but all elastic fluids, such as vapour and air, owe their existence in that state to the presence of heat; and that it is subject to all the laws of attraction, and is more forcibly attracted by some bodies than by others.

The school of Dr. Black seems to have considered light and heat as essentially different; and Dr. Scheele, a Swedish philosopher, has endeavoured to prove, that light is formed by an union of the matter of heat with phlogiston or the inflammable principle: but this theory is now exploded.

Upon the theory of Dr. Black, the late ingenious Dr. Crawford \* has founded a very curious system concerning

\* I cannot mention this truly amiable philosopher, without a short tribute to his memory, though it has apparently little connection

concerning the generation of heat within animal bodies, which he considers as derived from the air we breathe. The air being condensed on the lungs, the heat which it contained in a latent state is absorbed and dispersed over the animal body.—But this is a subject which properly belongs to another part of the work.

connection with the subject. No man was ever better calculated for promoting useful science than Dr. Crawford. In him industry and perseverance were established habits; and candour and caution characteristic dispositions. With all the advantages of a liberal education, he united great natural sagacity, acuteness, and ingenuity; yet the last quality was tempered by a coolness and collectedness of mind, which effectually prevented his too hastily acceding to the rash conclusions of plausible theory. With all his excellence as a scientific man, he possessed the gentlest of tempers, the most friendly heart.—From his promised revision of this work, I had flattered myself with great advantages; but what are private losses, compared with that of the public! If, after having served his country in a public capacity, the family of such a man should be left in indigence, to what a state is the national spirit reduced!

## C H A P. II.

## OF FIRE ( CALORIC ) AND ITS PROPERTIES.

*Inquiry whether Heat or Fire is a Substance or Quality.—Fire a Body.—Application of this Doctrine.—Analogy between Heat and Light—Objections.—Properties of Fire or Caloric; Minuteness of Particles; attracted by all Bodies.—Conducting Powers of different Bodies.—Cause of Fluidity.—Why Heat is produced by slacking Lime, and by certain Mixtures of cold Substances.—Freezing of Water by the Fire Side explained.—Fire the most elastic of all Bodies.*

**T**HE element of fire is only known by its effects; so subtile and evasive indeed is this wonderful fluid, so various are the forms which it assumes in the different departments of nature which it occupies, that its very existence, we have seen, has been questioned by some philosophers.

Heat, say these theorists, is nothing more than an intestine motion of the most subtile particles of bodies. Fire is no other than this motion increased to a certain degree, in other words, a body heated very hot; and flame is no more than ignited vapour, that is, vapour, the particles of which are agitated in an extraordinary degree.

In support of this theory it is alledged, 1. That motion in all cases is known to generate heat; and if continued to a certain degree, actual ignition will be produced,



produced, as the friction of two pieces of wood will first produce heat, and afterwards fire; and the motion of a glass globe upon an elastic cushion will cause a stream of fire to be copiously emitted. 2dly, Bodies which are most susceptible of intestine motion, are most readily heated. 3dly, Motion always accompanies fire or heat, as is evident on mixing oil of turpentine and vitriolic acid; and the heat seems in most cases to bear a proportion to the degree of motion or agitation. In the boiling of water, and in the hissing of heated iron when applied to a fluid, this motion is evidently manifested. 4thly, If the particles of any body are excited to a violent degree of intestine motion, by attrition, fermentation, &c. if they do not actually emit flames, they will yet be disposed to catch fire with the utmost facility; as in the distillation of spirits, if the head of the still is removed, the vapours will instantly be converted into flame if brought into contact with a lighted candle, or any other ignited body. Lastly, Heated bodies receive no accession of weight, which they apparently ought to do, on another body being introduced into their pores.

Plausible as this reasoning appears at first sight, the hypothesis which assigns existence to the principle of fire, as a distinct elementary principle, is supported by more numerous facts, and by more decisive reasons; it accounts better for all the phenomena of nature, and even for those very phenomena which are adduced in support of the contrary opinion.

1st. If it is admitted, as I apprehend it must, by the advocates for the contrary opinion, that the internal motion or agitation, which they say constitutes heat, is not equally felt by all the component particles of bodies, but only by the minuter and more subtile particles; and that these particles being afterwards thrown into a projectile state produce the effect of light; these concessions will almost amount to the establishment of the principle of fire as an elementary principle.

2dly. That fire is really a substance, and not a quality, appears from its acting upon other substances, the reality of which has never been doubted. Charcoal, in its natural state, contains within its pores a large quantity of air; but if charcoal is heated, this air is expelled by the fire, which assumes its place, and occupies the pores of the charcoal. The burning of lime also, which deprives it of a great part of its weight by expelling the fixable air, demonstrates that fire, as a substance, enters into the pores of the lime, and forces out those other substances which are least intimately combined with it.

3dly. All the evidence of our senses, and many indubitable experiments, prove that light, which many suppose to be fire in a projectile state, is a substance. Boerhaave concentrated the rays of the sun in a very strong burning-glass, and by throwing them upon the needle of a compass, the needle was put in motion by the force of the rays, as it would have been by a blast of air, or a stroke from some other body. But this experiment was pursued with still superior success,

success, by a late ingenious philosopher \*. He constructed an instrument, in the form of a small vane or weather-cock. It consisted of a very thin plate of copper, of about one inch square, which was attached to one of the finest harpsichord wires, about ten inches long. To the middle of the wire was fixed an agate cap, such as is used for the smallest mariners compasses, after the manner of which it was intended to turn; and the copper plate was balanced on the other side by a grain of small shot. The instrument weighed ten grains; and to prevent its being affected by the vibrations of the air, it was inclosed in a glass box. The rays of the sun were thrown upon the plate of copper from a concave mirror of two feet in diameter; in consequence of which the vane, or copper plate, moved on repeated trials with a gradual motion, of about one inch in a second of time. This experiment I think a sufficient demonstration, if any demonstration was wanted, that light at least is a body. Of the identity of light, heat, and fire, I shall have occasion afterwards to treat.

4thly. The electric fire affects bodies with a true corporeal percussion †; and that this effect is not owing to the vibration of the air, or any medium but that of fire itself, is proved by many experiments

\* Mr. Mitchell.—See a fuller description of his instrument and experiments, in the Phil. Trans. and Priestley's Optics, p. 387.

† Jones's Physiol. Disq. p. 85.

in vacuo, &c. Now, if one species of fire is allowed to be material, there seems to be no reason why we should deny the same attribute to the rest.

5thly. It is not easy to conceive how a body can be expanded by motion alone; and it is much more natural to suppose, that bodies are expanded by the interposition of an extremely active and elastic substance between their component particles.

6thly. It is well known that there can be no ignition or combustion, that is, there can be no very high degree of heat, without a supply of air; a candle, for instance, will cease to burn in vacuo, or in air, the pure part of which is destroyed by burning or respiration. This is a fact which cannot be accounted for on the principle that all heat is no other than intestine motion; but is easily explained if we suppose fire a distinct elementary substance, which is contained in pure air, and is yielded by the air to the force of a superior attraction.

6thly. That heat is generally accompanied by motion, is no proof that heat and motion are the same; on the contrary, nothing is more natural than that the entrance of an exceedingly elastic substance into the pores of another body should excite some degree of intestine motion, as well as the emission of the same substance, which must occasion some degree of contraction in the particles of the body. Heat is indeed excited by the attrition of two pieces of wood; but why may not the fire in that case be expelled from the wood by the vibration

tion or contraction of its fibres \*, or from the air which occasionally interposes itself? In the same manner a piece of lead will become hot by hammering; but lead, and all metals, are known to contain a quantity of fire in a latent or combined state, which indeed occasionally causes their expansion or dilatation; it is then the more probable supposition, that the fire is expelled from the lead by the hammering and contraction of the metal, and this is rendered still more probable, since the contraction or compression of the metal in a vice will produce the same effect. The instance taken from the inflammability of the steam of spirituous liquors will be perfectly explained when I speak of steam or vapour; besides that, these liquors are among the most inflammable substances with which we are acquainted, and their particles, being in a rarefied state, will be more subject to those natural forces, which in all states are known to act upon them. There is no increase of gravity in heated bodies, because of the great elasticity of the matter of fire, which expands the bodies into which it enters, and consequently rather diminishes their specific gravities.

7thly. All the other phenomena of nature are more satisfactorily accounted for, on the principle that fire is a distinct substance, than on that which supposes it a mere quality, depending on the tremor or intestine motion of bodies.

\* If the parts of a body, containing any fluid, are made to vibrate strongly, they will in general expel a part of the fluid out of the pores.—*Nicholson*, Vol. II. p. 122.

Heat and light are the only means by which we are enabled to discover the presence of fire; I conclude, therefore, that they are both effects of the same cause. The rays of the sun, when concentrated to a certain degree, produce intense heat; and heat, when violently excited by attrition, &c. if the body in which it is excited is in favourable circumstances, will generally terminate in flame, and consequently in the emission of light. This hypothesis receives a strong confirmation from an experiment of Mr. Boyle. He coloured the surface of a large tile, one half white, and the other black: after suffering it to lie for some time, exposed to the summer sun, he found that while the whited part of the surface, or that part which reflected back the rays of light, remained quite cool, the black part, which imbibed them, was grown extremely hot. He occasionally left a part of the tile of its native red; and, after exposing the whole to the sun, found that this part grew hotter than the white, but not quite so hot as the black part. He observes, that rooms hung with black are not only the darkest but the warmest also; and a virtuoso of unsuspected credit assured him, that in hot climates he had seen eggs well roasted in a short time, by only blacking the shells, and exposing them to the sun. This fact was afterwards completely established by Dr. Franklin, who exposed several pieces of cloth of different colours upon the surface of snow; he found that the black sunk considerably beneath the surface, consequently that

that it imbibed a large quantity of heat, whereas the white, which reflected the greater part of the rays of light, had imbibed scarcely any heat whatever.

The only objection of any moment, which has arisen against this doctrine is, that there exist certain bodies, such as what are called the solar phosphori, putrescent substances, and rotten wood, which emit or reflect light, without apparently possessing the smallest quantity of sensible heat. If however we consider the extreme weakness of the light which is emitted by these substances, the objection will appear to have little force. The most concentrated moonlight, in the focus of a concave mirror, is not more than the three hundredth part of the intensity of common sunshine\*; and yet the light from these substances is not to be compared with that of the moon. Nay, the analogy between heat and light receives confirmation from these very substances; for the property which they possess of emitting light, is greatly increased by an accession of heat; and even phosphori, in which the light has for some space of time been dormant, or in which it is apparently exhausted, will emit light upon the application of heat alone†.

I conceive fire therefore, or caloric, as termed by the French chemists, to be the elementary principle or cause of heat and light. Fire in a disen-

\* See a note by the ingenious translator of Fourcroy's Lectures. Vol. I. p. 123.

† Priestley's Optics, part iv. § 1.

gaged state, or in the act of passing from one body to another, impresses our organs with the sense of heat; and fire, in a rarefied and projectile state, probably constitutes the matter of light. Consistently with these principles, the sun may be considered as the great source of fire, whence it is distributed to all the different bodies in our solar system. On the same ground also, cold is universally allowed to be a mere negative quality, and to mean nothing more than the absence of heat or fire.

It appears the most convenient form of treating this important subject, first to consider fire in its capacity of exciting heat and producing expansion; and secondly, to direct our attention to the various phenomena which it exhibits in its combined state, as the efficient cause of fluidity both in the incompressible and elastic or aerial fluids. I shall first enter into a brief detail of the principal and known properties of fire, caloric, or heat; and shall afterwards illustrate these properties by its effects in different instances.

First. The particles of *fire* appear to be more *minute* than those of any other substance whatever. It penetrates all bodies with the utmost ease. If the pores of a body are disposed in right lines, so as to admit the passage of fire without impeding its velocity, it will be transmitted in the state of light as well as in its ordinary state, when it excites the sensation of heat, as is the case with all transparent or diaphanous bodies. But there is no body, however dense, which will not admit this element to

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circulate



circulate through its pores with the utmost rapidity. A piece of charcoal screwed up fast in a vessel of iron will be ignited as effectually as in the naked fire. Those bodies which most completely exclude the air, are utterly unable to resist the entrance of fire: for a thermometer will rise equally in the most complete vacuum that can be produced, as in the open air \*.

2dly. The matter of fire is attracted more or less by all bodies. When any heated body comes in contact with a cold one, the former loses a part of its heat, and both of them become equally warm. If heated iron is laid upon a stone, its heat will flow into the stone; if thrown into water, the heat will be diffused through the water. If a number of different substances, as metals, wood, wool, &c. are brought together into a place where there is not a fire, if they are of different temperatures, that is, of different degrees of heat, the fire will be attracted from the hottest to those that are colder, till the perfect equilibrium is restored, or till they have all acquired the same temperature, as may be proved by applying the thermometer successively to each of them.

It does not appear, however, that all bodies have an equal attraction for the matter of fire. If a rod of iron is put into the fire for a short time, the end which is at a moderate distance from the fire will almost burn the hand; but a rod of wood, of the

\* See Jones's Phys. Disq. p. 88.

80 *Conducting Power of different Bodies.* [Book II.]

same length will be consumed to ashes at the end which is in the fire before the other end is sufficiently heated to burn the hand. A ball of lead and a ball of wool may be of exactly the same temperature by the thermometer, but they will not appear of the same degree of heat on applying the hand. If they are of a temperature below that of our bodies, the lead will appear much colder than the wool, because it attracts the heat more rapidly from the hand; if they are of a higher temperature, the lead will appear much hotter, from the facility with which it parts with its heat. This property in bodies is called their *conducting* power; and those bodies through which the element of fire most rapidly circulates, are called good conductors.

The power of conducting the matter of fire seems to depend upon the texture of bodies, that is, upon the contact of their parts\*; hence the excessive slowness with which heat is communicated to bodies of a rare and spongy texture. Thus flannel, wool, and feathers, are considered as warm coverings, not because they possess more heat in themselves (for they serve to preserve any cold body in a cool state better than other substances) but because they prevent the escape of the animal heat from our bodies. It is a well-known fact, that ice is generally

\* This is proved by an easy experiment:—If a cube and a sphere of the same metal are put upon a plane intensely heated, the heat will flow faster into the cube; and if the same bodies are previously heated, and exposed on a cold plane, the cube will cool soonest.

kept in ice-houles in straw, or wool, those substances, from the rarity of their parts, preventing the entrance of the heat. On the same principle the ground is kept warm by snow, that substance being of a soft and spongy texture. It is true it will not keep the ground warmer than the freezing point; but that is warm, when compared with the intense cold which is occasionally experienced in most northern climates.

An ingenious and accurate experimentalist has lately endeavoured to estimate the conducting power of different bodies. The conducting power of mercury he found to be to that of water, as 1,000 to 313. Hence it is plain why mercury appears so much hotter or so much colder to the touch than water, at a time when they are evidently of the same temperature by the thermometer. Common air is a much better conductor than the Torricellian vacuum\*; its conducting power, compared with that of the vacuum, is nearly as 1,000 to 605.

A moist air conducts the matter of fire with much greater rapidity than a dry air; but the rarity or density of the air appears to have little effect upon its conducting power.

\* Made by filling a tube, closed at the top, with mercury, and emptying the upper part of the tube by immersing the lower in a vessel filled with the same fluid, as is the case in the common barometers. This is the most perfect vacuum we can make.

## §2 Conducting Power of different Bodies. [Book II.]

The proportion of the conducting power in the different substances which were the objects of his experiments, is as follows :

Mercury	-	-	-	-	-	-	-	1,000
Moist air	-	-	-	-	-	-	-	330
Water	-	-	-	-	-	-	-	313
Common air, the barom. at 27 inc' 9 lines								$80\frac{41}{100}$
Rarified air, - barom. at 6 - 11 lines								$80\frac{23}{100}$
The same, - barom. at 1 - 2								78
The Torricellian vacuum	-	-	-	-	-	-	-	55*

From the different effects of bodies upon our feelings, according to their conducting powers, arises the distinction which philosophers have made between absolute and sensible heat. It will be remembered, that the sensation of *hot* is the entrance of fire or heat into our bodies, and the sensation of cold is its departure from them †. These circumstances render the senses of animals a very inaccurate measure of heat; especially if we consider further, that much will also depend upon the state of the organ of feeling at the particular time. Water, at the temperature of 62°, appears cold to a warm hand; but it will appear warm to a hand which is of a lower temperature ‡. Travellers, therefore,

\* Sir Benj. Thompson's (now Count Rumford) Experiments on Heat. Phil. Transf. vol. lxxvi.

† The sudden and unexpected application of an extremely cold substance to the human body, produces a sensation very similar to that of a hot one.

‡ Crawford on Animal Heat, p. 5. 2d edit.

from

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from a warm to a cold country, will have sensations very different from those who travel in an opposite direction, should they happen to meet, as they frequently do, in a temperate climate. It is evident that the travellers from a cold climate, being deprived of less heat than usual, will have the sensation of warmth; and the others, on the contrary, will experience a degree of cold sufficient to excite considerable uneasiness.

3dly. The matter of fire will exist in a state of combination. I do not contend for the term chemical combination, in the strict and literal sense of the word; it is sufficient if it can be proved, that fire may exist in bodies in a *latent* state, or in a state not perceptible to our senses. It will be found by observation, that every body which exists contains a quantity of the matter of fire in this fixed or neutralized state, disarmed of all its active, penetrating, and destructive qualities, like an acid and an alkali in combination. If the coldest bodies with which we are acquainted are condensed or brought into a smaller compass, a quantity of fire will be emitted. If a piece of lead or iron is beaten with a hammer, or compressed in a vice, so as to force it to contract its dimensions, it has been already remarked that a degree of sensible heat will be produced.

Fluids, from their very nature and constitution, contain a greater quantity of fire in a latent state than solid bodies: indeed it is now universally admitted, and may be easily proved, that the fluidity of all bodies is altogether owing to the quantity of

fire which they retain in this latent or combined state, the elasticity of which keeps their particles remote from each other, and prevents their fixing into a solid mass. All bodies, therefore, in passing from a fluid to a solid state, emit a quantity of fire or heat. When water is thrown upon quick-lime, it is absorbed by the lime, and in this state it is capable of retaining a much smaller quantity of fire than in its natural state; on the slacking of lime therefore a very intense heat is produced, the fire which preserved the water fluid being disengaged and detached. If spirit of vitriol is added to strong oil of turpentine, they will condense into a solid mass, and a great quantity of heat will be sensibly emitted. If water is exposed to freeze, and a thermometer applied to it, during the act of freezing, or passing from a fluid to a solid state, it will be found several degrees warmer than the air which surrounds it, which is owing to the heat or fire emitted by that part of the water which is converted into ice. This effect is still more apparent from the condensation of the elastic fluids, which, from their rarity, contain a greater proportion of the matter of fire.

Upon the same principle it will be found, on the other hand, that when any body passes from a solid to a fluid state, the adjacent bodies will be deprived of a quantity of their natural heat. Thus if a quantity of aqua-fortis is poured upon solid ice, the ice immediately liquifies, and an astonishing degree of cold is instantly produced, even by the fire-side: this effect is altogether owing to the quantity  
of

of heat which is absorbed by the congealed water reassuming its fluid form. This experiment will serve to explain the fact that a thaw is generally colder than the commencement of a frost. The absorption of the matter of fire is further exemplified in the instance of bodies passing from the state of a common fluid to that of vapour, or an elastic fluid. If a thermometer is immersed in spirit of wine, in water, or in any fluid that easily evaporates, and is afterwards taken out and suspended in the air, the thermometer will sink two or three degrees, though the temperature of the air and water should be exactly the same: the fact is, the small quantity of fluid which remains on the bulb of the thermometer is carried off in vapour, and in that case the mercury within the thermometer is deprived of a certain portion of its latent fire. If the thermometer is repeatedly dipped in the fluid, the cold which is produced will be considerable. If ether, which is a very volatile fluid, is applied to any part of our bodies, cold is immediately produced; and on the same principle, a man may be frozen to death in very warm weather, by exposing him to continued evaporation; which may be effected by throwing repeatedly upon his body a quantity of ether, of spirits of wine, or of any other fluid which is easily evaporable. It is a common practice in China to cool wine or other liquors by wrapping the bottle in a wet cloth, and hanging it up in the sun; the water in the cloth is gradually converted into vapour, to form which the liquor in

the bottle is deprived of its latent fire. The celebrated Muschenbroek was astonished at the freezing of a wet cloth which was hung up to dry, when there was no appearance of frost in the atmosphere: the solution of the difficulty is, the temperature of the air at the time must have been within some degrees of frost, and the temperature of the cloth was suddenly reduced to the freezing point by the loss of a part of its heat from evaporation.

Let it be remembered, that in all these instances there is an evident accession or increase of the matter of fire thrown into the bodies which are rendered fluid, and yet the temperature or obvious heat of the fluids is not increased, as may be proved by the thermometer; wherefore it is plain that the fire exists in these substances in a *latent* or combined state.

4thly. The matter of fire is elastic, as is proved evidently from all its effects. There is indeed reason to believe that fire is the only fluid in nature which is permanently elastic; and that it is the cause of the elasticity of all fluids which are esteemed so.

From the elasticity of this element it results that all natural bodies can only retain a certain quantity of it, without undergoing an alteration in their state and form. Thus a moderate quantity of fire admitted into a solid body expands it; a still larger quantity renders it fluid; and if the quantity is still increased, it will be converted into vapour. But this, and all the other properties of fire, will be better understood



understood from its effects. Let it suffice to remark for the present, that most fluids may be converted into a state of unusual rarity, by the accession of fire. Vapour is 1800 times less dense than water; and those matters which have a stronger attraction for fire may by the same means be converted into fluids permanently elastic. The nitrous acid is wholly convertible into two species of air, oxygen and azote, or pure and phlogisticated air; and oils, resins, charcoal, and other inflammable matters, will by the application of heat readily assume the form of inflammable air. ●

## C H A P. III;

## O F E X P A N S I O N .

*Experiments proving the expansive Force of Fire, or Caloric.—Instruments for measuring Degrees of Heat.—Thermometers.—Dr. Black's Mode of measuring high Degrees of Heat.—Mr. Wedgwood's.*

**F**IRE, as was intimated in the preceding chapter, expands all bodies which it penetrates, more or less, in proportion to its quantity, and to the nature of those bodies. The expansion of water, even previous to its assuming the form of vapour, may be seen in an easy experiment. If a quantity of cold water, contained in a clear flask, is immersed in a vessel of boiling water; as the heat enters, the water in the flask will be seen to rise in the neck till it overflows.

An iron rod a foot long being heated red hot, became  $\frac{1}{80}$ th longer than before; and a glass cylinder, a fathom long, under the same circumstances, gained  $\frac{1}{30}$ th in length. A metalline ring thus heated was increased  $\frac{9}{100}$  in its diameter: and a glass globe became extended  $\frac{1}{100}$  part by the heat of the hand only applied to its surface \*.

\* Boerhaave's Chem. by Shaw, Vol. I. p. 299.

It is a well-known practice to immerse razors, or any instruments which are required to cut smooth, in warm water; as the whole of the metal expands, the edge is also proportionably expanded, and consequently is rendered so much finer and smoother.

An instrument was invented by Mr. Jones; for measuring the force of expansion, which by the flame of a farthing candle was able to lift a weight of five hundred pounds, without any assistance from the mechanical powers; and he shews that the same insignificant power, namely, the flame of a small candle, would by the force of expansion overcome a weight even of five thousand pounds, could an instrument be conveniently fitted up for the experiment\*. Indeed, when we consider that the force of cohesion in metals is so immense as to enable a gold wire of one-tenth of an inch diameter to support five hundred pounds weight, and an iron wire of the same dimensions to support one thousand five hundred pounds, without producing any separation of the parts; what must be the force of fire, which can relax and even dissolve the texture of the firmest metals†?

It is a fact universally known, that clocks and time-pieces in general go slower in warm weather, and faster in cold; this effect is owing entirely to the expansion of the pendulum, which being lengthened by the accession of heat or fire in warm weather, makes a longer vibration, and consequently loses a proportionate quantity of time; on

\* Jones's Phys. Disq. p. 99, 100.

† Ib. p. 98.

the

the contrary, the length of the pendulum being contracted by cold, the vibrations will be proportionably quicker, though the quantity of time gained or lost in a single vibration may be exceedingly trifling; yet as the vibrations are very often repeated, the effect will in a course of time be very considerable. An alteration of one hundred thousandth part in the time of a single vibration, will amount to nearly that of a whole vibration in the course of a day\*.

The cases are so numerous in philosophy and the arts, when it is desirable to be informed of the quantity of heat which exists in bodies, that it soon became an object of the utmost importance, to discover an accurate method for ascertaining it. The expansive property of fire was the property which most naturally suggested itself as likely to furnish an easy method of accomplishing this object, since the evidence of our senses assure us that, at least in all lower degrees of temperature, the expansion of bodies bears some degree of proportion to the quantity of the matter of fire which they have imbibed.

Air, as was intimated in a preceding chapter, was the first fluid which was employed as a measure of heat and cold. A small tube was prepared, open at the top, into which a quantity of coloured liquor was introduced; a quantity of air was left in the lower part of the tube, below the liquor, and in propor-

\* Jones's Phys. Disq. p. 98.

tion as this air expanded or contracted, the heat of the surrounding medium was supposed to be increased or diminished. The manifest inconvenience attending this instrument was, that as the upper orifice of the tube was necessarily left open, it was liable to be affected by two causes, by the natural heat of the medium, and by the weight of the atmosphere pressing upon the liquor in the upper part of the tube.

The next fluid that was made use of was spirit of wine, and this, being inclosed in a tube which was exhausted of air, afforded an instrument much more perfect than the former. The principal objection to this species of thermometer is, that spirit of wine is incapable of enduring any great degree either of heat or cold, since it boils in vacuo at fifty-two degrees. This thermometer is distinguished by the name of the Florentine thermometer, as it was invented by some of the members of that academy. It was afterwards greatly improved by the celebrated M. Reaumur, who proportioned the expansibility of the liquor to the size of his tube, by diluting it with water, or the contrary; the generality therefore of thermometers made with spirits of wine are termed Reaumur's thermometers.

Oil was employed by Sir Isaac Newton instead of spirit of wine, as being capable of a greater degree of expansion, since that fluid will bear about four times the heat of boiling water before it boils, and in general a very great degree of cold is required to make it freeze. The principal objection to Newton's

ton's thermometer arises from the viscosity of the oil, which occasions it to adhere to the sides of the vessel, so that a considerable quantity of the fluid being retained by the glass, when the thermometer sinks it appears to sink lower at first than it ought to do, according to the natural temperature.

These thermometers, therefore, were all of them superseded by the famous invention of Olaus Roemer, improved by Fahrenheit, who substituted mercury instead of the other fluids. Mercury is found to be a more homogeneous body than any other fluid, and more regular in its expansions, besides that it is capable of exhibiting a more copious scale of both heat and cold.

Sir Isaac Newton, observing that water uniformly froze with a certain degree of cold, and as uniformly boiled when the heat was increased to a certain degree, took what is called the freezing point for the commencement of his scale, and from that to the boiling point he counted thirty-four degrees, and divided his scale accordingly. It is evident, however, that even in this climate we have many degrees of cold below the freezing point. Reaumur, therefore, though he commenced his scale also at the freezing point, yet admits of several degrees below it, and proceeds both ways from 0; the boiling point in his scale is at 80° above 0. The scale of Fahrenheit begins considerably below the freezing point, at that period of cold which is produced by surrounding the bulb of the thermometer with a mixture of snow or pounded ice and sal ammoniac or sea-salt: he divided

vided his scale into minuter portions than either Newton or Reaumur, on which account it is well known that the boiling point in Farenheit's thermometer is at  $212^{\circ}$ . Sir Isaac Newton's thermometer is, I believe, now quite obsolete: Reaumur's is still used by many of the French, and other experimentalists. The degree of heat, however, when noted on either of these instruments, may easily be computed, by remembering that  $34^{\circ}$  of Newton's answer to 80 of Reaumur, and to 212 of Farenheit; and that the freezing point, which is the commencement of both the other scales, is in Farenheit's at  $32^{\circ}$  above 0.

The graduating a mercurial, or Farenheit's thermometer, cannot, from what has been observed, be a difficult task. The mercury must be carefully purged from air, as that, being a more elastic fluid, would create some irregularity in the expansions of the metal, or would collect in the upper part of the tube, which ought to be the most perfect vacuum that can be formed. It is well known that what is called the *Torricellian*\* vacuum is formed by filling a glass tube with mercury, and then inverting the tube in a vessel of the same fluid, and withdrawing it slowly till the mercury subsides, by which means all that part of the tube which is above the mercury will be free from air; on withdrawing the tube out of the mercury, it is obvious that the orifice must be stopped with the finger or some other stopper, to prevent the air from rushing in. When by these

\* From Torricelli, the inventor.

means a quantity of mercury is included in a glass tube with a small bulb, the glass may be easily closed by applying an ignited charcoal and a blow-pipe, such as the jewellers make use of, which melts the glass, and enables us to twist it round, in such a manner as completely to close it against the admission of air; and this operation is called *hermetically* sealing it \*. In order to graduate the thermometer; it must be first immersed in a mixture of pounded ice or snow and sal ammoniac, and the point at which the mercury settles must be marked as the commencement of the scale, or 0. It is next to be immersed in boiling water, and that point is to be marked  $212^{\circ}$ , and the intermediate part of the thermometer must be divided into this number of degrees.

Thermometers with small bulbs, and proportionable cylinders, are most useful, since a large volume of mercury requires a considerable time to heat and cool. It is also accounted a favourable circumstance when that part of the bulb which is adjoining to the tube is rather of a conical form.

That the thermometer is a true measure of heat, is proved by some very satisfactory experiments: If equal quantities of hot and cold water are mixed together, the heat of the mixture will be nearly as

\* It is easy to prove whether the tube is a perfect vacuum or not, after it is hermetically sealed, by merely inverting it, and observing whether any bubble of air remains to resist the mercury's falling to the bottom of the tube.



the mean heat of the two component parts \*. This fact was ascertained by a still more accurate experiment of Dr. Crawford, who contrived a method of combining the boiling and freezing points together, and found that the degree of heat communicated to the thermometer was as nearly as possible the arithmetical mean †.

It is evident, from the nature of expansion, that thermometers might be constructed of solid bodies. Metallic thermometers have indeed occasionally been made, and graduated for different purposes; but their utility is necessarily very limited, since solid bodies are expanded with much more difficulty, and in a less degree, than fluids.

Though the mercurial thermometer is so much more perfect, and is capable of exhibiting much higher degrees of heat than those which had been in use before the time of Farenheit; yet as mercury boils at 600°, that is, considerably below the red heat of iron, and as it is plain that no fluid can afford any true measure of heat beyond that point in which it is itself converted into vapour, it is equally plain, that there must exist several degrees of heat which cannot possibly be exhibited by the mercurial thermometer. These degrees are very

\* This experiment was originally made by Dr. Brook Taylor. It was afterwards repeated by M. de Luc, and by Dr. Crawford; who, from the impossibility of conducting the experiment without loss of time, found the heat of the mixture always below the arithmetical mean.

*Crawford on Heat, p. 18, et seq. 2d edit.*

† *Ib.* 47, 48.

96 *Mode of measuring high Degrees of Heat.* [Book II.

inaccurately defined by the chemists and artists, according to the appearance, terming them a *red* and *white* heat, &c. To remedy the inconveniences resulting from the want of a definite standard of heat above the point of boiling mercury, several methods have been proposed, but there are only two which I esteem worthy of notice.

A very eminent philosopher, who may be termed the father of the modern doctrines concerning heat, proposes, in order to ascertain the heat of any given furnace, for instance, to heat some body (the dimensions of which may be easily taken) in that furnace, and when heated to plunge it into a quantity of cold water, and multiply the degree of heat by the proportion which the bulk of the water bears to that of the body heated. Thus, if a piece of iron is taken *red hot*, and thrown into a quantity of water 100 times its bulk, when the heat which was concentrated in the iron is diffused through the whole quantity of water, it is evident that the temperature of the water thus heated, multiplied by 100, will give the heat of the iron when red hot.

Another mode of ascertaining high degrees of heat has been proposed by the late Mr. Wedgwood, who by means of a distinguishing property in argillaceous bodies, namely, that of contracting when exposed to fire, was enabled to construct a new thermometer for this purpose. The sensible contraction of earthen-ware commences at a low red heat, and proceeds regularly till the clay becomes vitrified. Mr. Wedgwood's thermometer, therefore,

fore, consists of a small portion of this clay, properly baked, and so nicely adapted to a brass gage, that the clay is permitted to slide along the gage in proportion as it is contracted by the fire. He divided his scale, from the degree of heat at which the clay begins to contract, to the greatest degree of heat he was able to produce, into  $160^{\circ}$ . By this instrument he found, that copper melted at  $27^{\circ}$ ; silver at  $28^{\circ}$ ; gold at  $32^{\circ}$ ; cast iron at  $130^{\circ}$ .

## C H A P. IV.

## O F F L U I D I T Y.

*Caloric equally the Cause of Expansion and Fluidity.—Phenomena of Bodies passing from a solid to a fluid State, and the contrary.—Intense Cold of the Southern Hemisphere explained.—Distinction between Expansion and Fluidity.—Experiments illustrative of the Doctrine of latent Heat.*

**I**T was intimated that all bodies are capable of containing only a limited quantity of fire, without undergoing an alteration in their external form; the same cause which produces expansion, being increased to a certain degree, produces a total dissolution of the parts of bodies, and reduces them to a fluid state; and a further increase of the same power renders them volatile, or causes them to be carried off in the form of an elastic fluid, such as air or vapour.

After what has been formerly stated, it will be no difficult matter to conceive the cause of all these effects to be the same. The subtile matter of fire, which appears to be the only substance in nature which is permanently elastic, or between whose particles a natural repulsion exists, insinuating itself between the particles of bodies, destroys or rather counteracts the natural power of attraction or cohesion, which impels the particles of bodies to approach

approach as nearly in contact to each other as possible. When a body is reduced from a solid to a fluid state, a quantity of heat or fire is absorbed from some of the surrounding media. The nature of fluids would therefore be, perhaps, not improperly described, by supposing them to consist of the very minute particles of the bodies from which they are produced kept floating in a quantity of fire. To understand how fire may exist in this combined state, without exhibiting any of its destructive properties, let it be remembered, that fire, like every other body, can be only active while in a disengaged state. Fire cannot excite in our organs the sensation of heat, unless it penetrates those organs; if therefore it is retained by another body by the force of a superior attraction, it is evident it cannot affect our organs as it would if in a state to be attracted by them. In the same manner the mineral acids (aqua-fortis for instance) in a disengaged state act with violence on almost every substance, and corrode or ulcerate our flesh, when brought in contact with them; but if united with a body which possesses a stronger attraction for them (such as an alkali) they will not leave that body to act upon any other, but are perfectly disarmed of all their noxious qualities: thus the safe and innocent compound saltpetre is formed from two violently active and corrosive substances, a caustic alkali, and the nitrous acid, or aqua-fortis; and common salt from the same alkali, and the muriatic acid.

Every body in passing from a solid to a fluid state, or from that of a common to a rarer or elastic fluid, absorbs a quantity of caloric or fire, and consequently a degree of cold is always produced by the process; and on the contrary, every body in passing from a fluid to a solid state, or from that of a rarer to that of a denser fluid, emits a quantity of that fire which kept it in a state of fluidity; and by this process, on the other hand, a proportionable degree of sensible heat is produced.

A number of phenomena, which were before unexplained, are now clearly illustrated by this theory. What is called the freezing mixture, it is well known consists of a quantity of pounded ice or snow with aqua-fortis, or any saline substance. The immense cold which is suddenly produced by this process, is owing entirely to the sudden liquefaction of the ice, in which case all the adjacent bodies must supply a quantity of caloric or fire, which is absorbed by the melting ice, and retained by the fluid in a latent state, or state of combination. Cold is produced by evaporation, on the same principle, the quantity of elementary fire which is attracted by a fluid when passing into a rarer state, and which is required to form atmospheres of fire round the particles of the body, so as to keep them suspended in the fluid form, is necessarily supplied from the surrounding bodies, and must be attended with a degree of cold.

The southern hemisphere is remarkably colder than that of the north, and even in the midst of  
summer

summer an excessive degree of cold has been found in the regions which lie near the antarctic circle. To account for these phenomena, we must probably have recourse to two causes. As there is a greater extent of water in that hemisphere, the evaporation is considerably greater than in that of the north; and as the southern ocean abounds with a multitude of immense ice islands, the continual melting of the ice absorbs the matter of fire from all the circumjacent atmosphere; and in fact we are informed by mariners, that the cold is considerably increased by the approach of one of these floating mountains of ice. Partly for the same reason a thaw is observed to be much colder than a settled frost; though it is also to be remembered, that the atmosphere is always rather inclined to damp in a thaw, and a damp air is a much more powerful conductor of heat than a dry one.

On the contrary, when a fluid body passes into a solid state, a quantity of fire is necessarily extricated. The heat produced by slacking lime has sometimes been so great as to fire wood; in this case it has already been shewn, that the component particles of the water being absorbed by the lime, the fire which held it in fusion is expelled. A mixture of the essential oils with spirit of vitriol produces the same effect; the mixture forms itself into a solid mass, and the fire which the fluids contained is suddenly extricated. A quantity of water will often continue fluid at some degrees below the freezing point, but by agitating the water it forms suddenly into

ice, and the fire which the fluid contained being set free, the thermometer will rise some degrees. The air is often observed to be peculiarly mild during a fall of snow; the reason is, that the caloric which the water of the snow contained is discharged by its passing into a solid state, and sensible heat is produced. The union of a caustic alkali, which contains no fixed air, with an acid, excites great heat, in the same manner as when water is thrown upon quick-lime; but if the alkali is mild, that is, if it contains a quantity of fixed air, that substance going off in an aerial form absorbs the matter of fire, which it carries off with it, and no heat is generated \*.

It was stated, that expansion and fluidity are produced by the same cause: there is, however, this difference in the effects, that in expansion there is a regular increase or extension of bulk, according to the degree of heat; whereas the transition from a fluid to a solid state, or the contrary, is sudden; and below or above a particular point of temperature, a body always remains fluid or solid. There are, it is true, some bodies which appear in an intermediate state of fluidity, such as wax, tallow, &c.; yet even in these the point at which they become fluid is a settled point, though the different stages of softness depend upon the degrees of heat.

In expansion also the sensible heat is increased in proportion to the effect; but it is different in fluidity;

\* See Dr. Higgins's excellent Experiments and Observations, p. 319.



dity; for when bodies are arrived at the melting point, or point of fluidity, a large quantity of elementary fire is absorbed, without producing any sensible heat, or altering the temperature of the body. This absorption of the matter of fire frequently continues a considerable time, according to the supply from the adjacent bodies. Thus, when a thaw comes on, the heat is often far above the freezing point; and though the ice melts slowly, it is constantly surrounded by air warmer than itself, and constantly imbibing the matter of fire from it. On the other hand, if a quantity of boiling water is thrown upon ice, it will immediately melt; which proves that there is no difficulty in separating the particles of ice, if a sufficient quantity of heat is supplied: but the reason of these facts will be rendered clearer by the following experiments.

If a pound of water at  $32^{\circ}$  is mixed with an equal quantity of that fluid at  $172^{\circ}$ , the temperature of the mixture will be  $102^{\circ}$ , which is the arithmetical mean between the heat of the two fluids; but if a pound of ice at  $32^{\circ}$  is mixed with a pound of water at  $172^{\circ}$ , the temperature of the mixture will be  $32^{\circ}$ . Hence it appears, that in the melting of the ice one hundred and forty degrees of heat (that is, such a quantity of elementary fire as is necessary to produce that heat) are absorbed, or reduced to a state of combination, so as not to produce any effect on the thermometer\*.

\* Crawford on Animal Heat, p. 72.

The heat which the water absorbs in assuming its fluid form is again separated by congelation. If a pound of water at  $32^{\circ}$  is mixed with an equal quantity of ice at  $4^{\circ}$ , nearly one-fifth of the water will be frozen, and the temperature of the mixture will be  $32^{\circ}$ . In this experiment the ice is raised from  $4^{\circ}$  to the freezing point. It is therefore evident, in this experiment, that by the congelation of one-fifth of the water a quantity of fire is emitted sufficient to raise the heat of the ice nearly twenty-eight degrees; by the congelation therefore of a whole pound of water, a quantity of heat would be detached sufficient to raise it five times twenty-eight degrees. The caloric which is extricated by the congelation of the water is therefore precisely equal to that which is absorbed by the melting of ice\*.

There were disputes, in the time of Farenheit, concerning the rarefaction of ice, whether it depended on the air contained in it during its fluidity. He imagined, that if he extracted the air from water, he could produce an ice heavier than water. He extracted the air therefore from small glass globes filled with water. After exposing them to an intense cold, they were a long time in freezing, though cooled greatly below the freezing point; but upon breaking them to examine them, the air rushed in, which, from the sudden shock, occasioned the water instantly to freeze. He afterwards found, that simple agitation would produce the same effect.

\* Crawford on Animal Heat, p. 72.

If water which is freed from air, and which is perfectly at rest, is exposed to the atmosphere when it is colder than  $32^{\circ}$ , it will frequently sink eight or ten degrees below the freezing point, without undergoing any degree of congelation; but if the vessel is slightly agitated, a portion of it will immediately become solid, and the mixture of ice and water will be raised to  $32^{\circ}$ . The reason of this increase of temperature in the remaining water will be evident from the preceding experiments. By the freezing of a part of the water, a quantity of elementary fire, which existed in the fluid, is expelled, by its assuming a solid form; and this fire, being diffused among the remaining water, raises its temperature to the freezing point.

Different degrees of heat are required to retain different bodies in a fluid form. Water, mercury, and some other substances, are kept fluid by a degree of heat considerably below the ordinary heat of the atmosphere; and so great is the degree of cold which the latter endures, that, before the experiments of Professor Braun, of Petersburg, it was not supposed that it was capable of being frozen.

## C H A P. V.

## OF BOILING, VAPOUR, &amp;c.

*Elastic Fluids distinguished from common Fluids.—Specific Gravity of Vapour.—In what Manner Dr. Black was led to form his Theory of latent Heat.—Immense Force of Vapour.—Boiling.—All Fluids boil in a less Temperature in Vacuo, than under the Pressure of the Atmosphere.—Experiments.—Phenomena of Boiling and Evaporation explained.—Why Water extinguishes Flame.—Spontaneous Evaporation.—Phenomena of Dew, Mists, &c.*

**I**F the matter of fire is accumulated to a certain degree, the substance which is exposed to its action will be converted from the state of a common fluid to that of an elastic or compressible fluid, generally transparent, and extremely rare and light.

Vapour or steam, which is water converted into an elastic fluid, is of a specific gravity one thousand eight hundred times lighter than water; that is, a given portion of water will, in an elastic form, occupy one thousand eight hundred times the space it did before. The process of passing from the state of a common fluid to that of vapour, is called boiling; and the degree of heat at which a fluid begins to boil is called the boiling point, which, in water, is fixed on Farenheit's scale at 212°.

When

When a fluid arrives at the boiling point, and passes from its ordinary state to that of vapour, the same effect takes place as in the conversion of solid bodies into fluids, a quantity of caloric or elementary fire is absorbed without any increase of temperature; and when an elastic fluid is condensed, the same fire is constantly emitted, and sensible heat is consequently produced. If we observe the heating of water, we shall find that the heat flows into it very fast, till it arrives at the boiling or vaporific point. Suppose that in the last five minutes its heat is increased  $10^{\circ}$ , in the next five we should expect that it would at least be six or seven more; but this is not in reality the case, for though very little of the water is evaporated, yet the remainder is not sensibly hotter. In order to prove the time necessary to convert a quantity of water into vapour, a number of flat-bottomed cylindrical vessels of iron were constructed, into which a quantity of water was put, at the temperature of  $54^{\circ}$ . The water was heated to the boiling point in four minutes, but it was not evaporated in less than twenty. Thus it is evident that the water had acquired  $158^{\circ}$  of heat in the space of four minutes; and consequently, as the heat of the fire continued the same, it required five times  $158^{\circ}$  of heat to convert it into vapour. This immense accession of fire is, however, neither sensible in the water nor in the vapour, for if a thermometer is applied to the steam, it will not be found hotter than the boiling water, it is therefore really absorbed by the fluid, which

which is converted into vapour, and is retained in the latter in a combined state. When the vapour is condensed in the refrigeratory of a still, the latent or combined fire is once more rendered sensible, for the refrigeratory is heated much higher than the sensible heat of the vapour, as the heat, if accumulated, would raise the thermometer to more than 800°.

We are informed by Dr. Crawford, that Dr. Black, who is certainly the author of the present theory of heat and fluidity, 'was first led to the discovery of the absorption of heat by aqueous vapour, in consequence of an unexpected appearance which occurred in an experiment made with water at a high temperature. A quantity of that fluid having been raised in Papin's digester \* to a temperature many degrees above the boiling point †, was suffered to communicate with the external air, by opening a stop-cock, upon which a part of it was instantly converted into vapour, and the water at the same moment sunk to 212 ‡.' As it appeared however that only a very small quantity of the water had been carried off by this sudden evaporation, it was naturally concluded that the whole of the superfluous fire which the water had previously imbibed was absorbed by that part which assumed the form of vapour.

\* Papin's digester is an iron vessel, made particularly strong.

† I have been told to 412.

‡ Crawford on Animal Heat, p. 27.

The fact is accounted as established by the same philosopher from the following experiment. If eight pounds of the filings of iron at 212 are mixed with a pound of water at 32, the temperature of the mixture will be nearly 122; the iron will be cooled 90 degrees, and the water heated 90. But if eight pounds of iron filings at 300 are mixed with a pound of water at the boiling point, the temperature of the mixture will continue at 212, and a part of the water will be suddenly carried off in vapour, which vapour itself will be found to retain the same temperature of 212. In this experiment the temperature of the iron is lowered 88 degrees, without any apparent accession of heat to the water; the fair conclusion is therefore that the superfluous fire is absorbed and carried off by the vapour\*.

Vapour is an elastic fluid, that is, it admits of being compressed within a compass proportioned to the force which compresses it. Its force in resisting compression, when it is accumulated to a certain degree, is however greater than that of gunpowder, or of any power with which we are acquainted. Steam is therefore one of the most potent and most dangerous agents in nature. A small quantity of water thrown upon boiling oil, or introduced among metals while in fusion, produces the most formidable effects. The water sinks towards the bottom in the oil, where being converted into vapour, by the force of its expansion

\* Crawford on Animal Heat, p. 78.

it causes a most violent ebullition and explosion, and throws the heated fluid about with incredible velocity. Hence in casting iron or copper vessels, if the smallest particle of humidity is contained in the mold, or if the metal meets with any liquid in its passage from the furnace to the mold, it will be exploded with the utmost hazard to the workmen from the burning metal. We have an instance recorded in the *Philosophical Transactions*, of the bursting of one of Papin's digesters containing a pint of water, which demonstrates the amazing expansive force of vapour. The report on the bursting of the vessel was heard at a considerable distance by a maid servant who was milking the cows in an adjacent field, and the servants within said it shook the house; the vessel flew in a direct line across the room, and shivered an inch plank of oak in pieces: what is most extraordinary, no traces of water were to be found in any part of the room; the fire was however completely extinguished\*.

The force of the common steam-engine is well known†; and an instance recorded by Mr. Jones in his *Physiological Disquisitions*, serves well to mark its

\* *Phil. Tr. Abr.* vol. viii. p. 465.

† In these machines, the steam is conveyed into a large cylinder or barrel of iron, in which a very heavy piston of the same metal is raised: when the piston is to fall, the steam is suddenly made to collapse by the injection of some cold water, which immediately condenses it, and makes a vacuum, so that the piston is forced down again by the pressure of the atmosphere. By these alternate



its effects. ‘ A workman, who with some others was employed to repair a fire-engine at Chelsea, informed me, that as they were busy about it in working it to understand the defect, the barrel, which was of great capacity, and too much worn with long use, burst on a sudden, and a cloud of steam rushing out at the fracture struck one of the workmen who was standing by, and killed him in a moment like a blast of lightning. His fellows ran up as soon as they could to give him assistance, but when they endeavoured to take off his cloaths, the flesh came away from the bones along with them.’

Though all fluids are rendered elastic by fire, yet the quantity of fire necessary to raise them to a state of vapour depends upon different circumstances. The very nature of an elastic fluid renders it particularly liable to be affected by the weight which is incumbent upon it. All fluids therefore boil with a much less degree of heat in vacuo, than under the ordinary pressure of the atmosphere. Thus water moderately heated, and placed in the receiver of an air-pump, may be made to boil by withdrawing a part of the air by which it is compressed; and it will be observed to cease as soon as the air is re-

nate risings and fallings of the piston, several of which are performed in the space of a minute, the machine acts on the work of a forcing pump, by which the water is raised, and discharged at the proper place. This machine, considering the vast force of it, is one of the simplest in the world; but, like the digester, may become extremely dangerous if the fire by any accident should get the power over it.

turned,

turned, and the pressure restored\*. In the most perfect vacuum that we are able to procure water boils at 90, and spirit of wine at 52, that is at 122 below the boiling point under the common pressure of the atmosphere.

A pleasing experiment is related by that elegant and ingenious philosopher, the present Bishop of Landaff, which is illustrative of the nature of boiling in general, and particularly of what has been just advanced. With an intention of exhibiting a striking instance of the increase of dimensions produced by heat in fluids, he took a glass vessel, not unlike a thermometer in form; the bulb contained above a gallon, the stem had a small diameter, and was about two feet in length. This vessel be filled with boiling water to the very top of the stem, and corked it close with a common cork. The water and the cork were at first contiguous, but as the water cooled it contracted, and sunk visibly in the stem; and thus the first intention of the experiment was answered. But here an unexpected phenomenon presented itself. The water, though it was removed from the fire, though it was growing cold, and had for some time entirely ceased from boiling, began to *boil* very violently. When a hot iron was applied to that part of the stem, through which the water in contracting itself had descended, the ebullition presently ceased; it was renewed when the iron was removed; and it became more than ordinarily

\* Higgins's Experiments and Observations, p. 313.

violent,

violent, when by the application of a cloth dipped in cold water that part was cooled. To account for these appearances, it is only necessary to recollect that by the sinking of the water in the stem a kind of vacuum is left between its surface and the cork; the water therefore necessarily boils with a lower degree of heat than it would, under the pressure of the atmosphere. The space between the cork and the water is not however a perfect vacuum; it is occupied either by the vapour of the water, or by a small portion of air, or by both. Heat increases the elasticity both of air and vapour, and thus augments the pressure upon the surface of the water, hence the ebullition ceases upon the application of the hot iron. Cold, on the contrary, diminishes the elasticity of the air, and condenses vapour; and thus the pressure upon the surface being lessened by the application of a cold cloth, the ebullition of the water became more violent. The heat of the water when it ceased boiling was  $130^{\circ}$  \*.

An experiment of another distinguished philosopher affords perhaps a better illustration of the whole theory which has been just advanced. This gentleman placed a quantity of vitriolic ether under the receiver of an air-pump, which was so contrived that he was able to let down a thermometer at pleasure, without admitting the external air. He no sooner began to extract the air, than the ether was thrown into a violent ebullition, at the same time

\* Chem. Essays, vol. iii. p. 162.

its temperature sunk surprizingly. When the ether was first put in, its temperature was about  $58^{\circ}$ , but it became so cold when boiling, that a quantity of water in a vessel contiguous to it was suddenly frozen. The manner in which these phenomena may be explained is this:—The weight of the atmosphere being removed, the heat which the ether contained was sufficient to make it boil. The elementary fire which the ether lost in boiling was disposed of in forming a vapour more subtile than the ether itself; which could not, consistently with the principles established, be formed without the absorption of a considerable quantity of the matter of fire. Now as it appears that water and spirit of wine boil in vacuo at  $122^{\circ}$  below their ordinary boiling point, it is natural that ether, which boils in the open air at about the heat of the human blood, should boil in vacuo at  $24^{\circ}$  below 0, a degree of cold sufficient to freeze any water that might happen to be in contact with the vessel which contains the ether.

As the weight of the atmosphere varies some degrees at different times, it is evident, from these remarks, that the boiling point of fluids will also occasionally vary. Boerhaave supposes, that, according to the changes of the atmosphere, as marked by the barometer, the heat of boiling water may vary occasionally eight or nine degrees\*;

\* Boerhaave Chem. quoted by Watson. Chem. Ess. vol. iii. p. 157.

and we find the opinion confirmed by the accurate experiments of M. de Luc and Sir George Shuckburg, in the course of which the boiling point was sometimes lower than  $205^{\circ}$ , and sometimes higher than  $213^{\circ}$ .\*

Some of the phenomena of evaporation and boiling, not hitherto noticed, will receive a satisfactory explanation from this theory.—1st, If a single drop of water is heated to the vapourific point, it is immediately converted into vapour; but if the quantity is more considerable, the phenomenon will be varied: for, if a quantity of water is thrown into an iron vessel heated very hot, it will seem to run

\* This will be better understood by exhibiting Mr. Cavallo's table of the result of each experiment.

Height of the Barometer.	Heat of boiling Water, according to	
	M. de Luc.	Sir G. Shuckburg.
	Parts of a Deg. deg.	Parts of a Deg. deg.
26	205,17	204,91
26 $\frac{1}{2}$	206,07	205,82
27	206,96	206,73
27 $\frac{1}{2}$	207,84	207,63
28	208,69	208,25
28 $\frac{1}{2}$	209,55	209,41
29	210,38	210,28
29 $\frac{1}{2}$	210,02	211,15
30	212	212
30 $\frac{1}{2}$	212,79	221,85
31	213,57	213,69

Water boiling hot cools in six hours in the ordinary heat of the atmosphere.

about the vessel like quicksilver, but without touching the bottom or sides of the vessel. The reason is, that the water nearest the bottom and sides is converted into vapour, which prevents the fluid from coming in contact with the iron; and this is the reason also that a red-hot piece of iron dropped into water continues for some little time in the same red-hot state, the water nearest the iron being suddenly converted into an elastic vapour, which repels or keeps off the rest of the fluid.

2dly, The bubbling and hissing of boiling fluids, or of fluids upon the point of boiling, was unaccounted for till Dr. Black's theory elucidated the point. In the common mode of boiling water it is plain, that the bottom of the fluid arrives at the vapourific point of heat before the surface; a quantity therefore of the fluid which is nearest the bottom of the vessel is converted into vapour, which forcing its way through the superincumbent medium occasions that violent ebullion which always takes place when a fluid is heated to its vapourific point. The hissing of kettles and other vessels, previous to their arriving at the boiling point, is perhaps to be accounted for from these vapourific bubbles in their ascent meeting with the cold water, and discharging their fire, which condenses the vapour before it arrives at the surface, and occasions the feeble sound which has been just mentioned, without any considerable agitation of the fluid, or emission of steam.

3dly, The

3dly, The reason why water, either hot or cold, immediately extinguishes flame, will easily be understood from what has been premised. When a quantity of water is thrown upon an ignited body, it is immediately converted into vapour, and this process suddenly deprives the burning body of as much elementary fire as the vapour is naturally disposed to absorb. If therefore the water is applied in sufficient quantity, the whole of the fire will be imbibed by the evaporation, and the body will be left totally destitute of heat. For the same reason it is evident, that water will prevent the melting of metals, or of any substances which require a degree of heat superior to the boiling point, to render them fluid: for the water, being in contact with the other substance, will not permit its temperature to increase, and all the superfluous fire which would heat it above the boiling point, if the water was not there, is carried off by the evaporation of that fluid \*.

The

\* Perhaps it may not be quite unacceptable to the reader to notice in this place the vulgar paradox: "That when water is boiling in a vessel, the bottom is cool; but the moment it ceases to boil, the bottom becomes hotter." The whole of the paradox appears to be founded on an error of the sense. When a person applies his finger to the vessel, though he applies it for a considerable time, it is not heated more than he can endure, for the blood in the course of its circulation loses some of its heat before it arrives at the extremities; and till the blood in the extremities is heated to the same degree with that of the heart we feel no pain from burning; but as soon as this is effected, the least degree of heat becomes painful. When the finger is first applied to the bottom of the vessel after it is taken

The general process which bodies not highly inflammable undergo when subjected to the action of fire, is first to be reduced to a fluid state, and then to a state of vapour. There are, however, some bodies which are converted into vapour without at all assuming the fluid form, such as camphor, sal ammoniac, arsenic, &c. These, when exposed to fire, fly off in vapour, without being melted; which vapour, on condensation, becomes a solid mass again. These substances may therefore be said to have their vapourific point below that of their fluidity; and the reason of this appears to be, that their particles have a stronger attraction for the matter of fire than for each other. In fact, we find that these substances may be reduced to a fluid form by confining them in close vessels, where they may be forced to endure a greater degree of heat than under the pressure of the atmosphere. Camphor at least has in this manner been rendered fluid; and there is no reason why sal ammoniac, and all the volatile alkalies, might not be reduced to the same state; but from the great elasticity of the vapour, the process has not been completed for fear of bursting the vessels.

There are some bodies which have never hitherto been reduced to a state of vapour. Those

off the fire, the heat is endured for these reasons. When the boiling ceases, it is natural to take the same finger (for having dirtied one, people seldom chuse to take another) and that finger, being already heated almost as much as it could bear, now finds the heat at the bottom of the vessel exquisitely painful.



earthy substances which have been rendered fluid, have never, by any degree of heat, been rendered volatile, and there are some earths which have never been even brought into fusion. Some of the metals, particularly gold and silver, were thought formerly to be absolutely fixed. Mr. Boyle exposed a small quantity of each for two months to the heat of a glass-house furnace, and at the end of that time he found them not altered; they have since, however, been compelled to emit very sensible vapours by the more intense heat of a burning-glass: and as the diamond itself has been subjected to evaporation, it is not improbable that by a sufficient quantity of heat every other mineral substance might be fused and volatilized.

The vapour of water, and most other fluids, requiring a degree of heat above that of the atmosphere to keep it in a volatile state, is easily deprived of its superfluous fire; and its particles being no longer kept asunder by a superior force, yield to the ordinary impulse of attraction, and are condensed into the state of a common fluid. There are, however, permanently elastic fluids, which are maintained in their elastic state by the ordinary heat of this earth; and these by analogy we may conclude are composed of particles which have a weak attraction for each other, and are therefore preserved in this rare and volatile state by a moderate portion of the matter of fire interposed between them: of this kind is the air we breathe, and

some other fluids, of which I shall presently have occasion to treat \*.

It would be improper to dismiss this subject, without offering a few remarks on that species of evaporation which is termed spontaneous, as I apprehend it not to be essentially different from that of which we have been treating. It is evident that a quantity of humidity is continually and insensibly emitted by every body which contains any principle of moisture. If a glass of cold water, or any cold body, such as smooth marble, is exposed in a room when many people are assembled, its outside will be covered with dew; the walls of churches and other buildings which have not constant fires are covered with moisture in the same manner, and this moisture in both cases is produced by the cold body (the glass of water, the marble, or the wall) condensing the vapour with which the air is charged from the breath and perspiration of the company. Similar to this is the dew on the inside of windows, which in cold weather is frequently frozen, and assumes the forms of leaves, of trees, and of the most beautiful mosses.

Water cannot be exposed in open vessels without suffering a diminution of its bulk, and indeed in course of time the whole will be exhaled. The vapour however which is thus formed is not sufficiently elastic to produce any of the common effects

\* As the ordinary heat of our atmosphere is sufficient to keep water and some other substances fluid; so it serves to keep these bodies in a volatile state.

of vapour; for water will remain in bottles corked up without forcing the corks; the vapour stagnating over the surface of the water, prevents a fresh quantity from rising: indeed the mere force of gravitation would in general be sufficient to counteract the force of this spontaneous evaporation, was it not that the wind carries off the quantity which is exhaled, which would otherwise be suspended and stagnate over the fluid. This vapour, it is to be observed, proceeds always from the surface of bodies; and the greater the extent of surface, the more copious the exhalation: it is observed, therefore, to rise more copiously from a grassy plain, from the pores of a sponge, or from loose earth, than from any single surface; and it is always more or less in quantity, according to the temperature of the atmosphere.

The quantity of vapour which is raised in this manner from the earth, has been estimated by a very simple yet apparently accurate experiment of the Bishop of Llandaff. Having provided a large drinking glass, the area of the mouth of which was twenty square inches, he placed it with its mouth downwards on a grass plat which was mown close. The sun shone bright and hot, and there had been no rain for upwards of a month. When the glass had stood on the grass plat one quarter of an hour, and had collected a quantity of condensed vapour, he wiped its inside with a piece of muslin, the weight of which he had previously ascertained, and as soon as the glass was wiped dry the muslin was weighed. The  
medium

medium increase of weight from various experiments, between twelve and three o'clock, was six grains in one quarter of an hour from twenty square inches of earth. At this rate of evaporation, it is easy to see that, computing at seven thousand grains troy to one pint of water, and eight pints to a gallon, not less than one thousand six hundred gallons of water would be raised from one acre of ground in twenty-four hours. It may well be supposed that the quantity will be still greater when the ground has been drenched with rain. In order to prove this, the same judicious philosopher made two other experiments, one of them the day after the ground had been wetted by a thunder-shower; and to ascertain the circumstances more exactly, he took the heat of the earth by a thermometer laid on the grass, which in the first experiment was  $96^{\circ}$ , when the evaporation was at the rate of one thousand nine hundred and seventy-three gallons from an acre in twelve hours. The other experiment was made when there had been no rain for a week, and when the heat of the earth was  $110^{\circ}$ : this experiment gave after the rate of two thousand eight hundred gallons from an acre in twelve hours; the earth was hotter than the air, being exposed to the reflexion of the sun's rays from a brick wall\*.

It is the vapour which is exhaled in this manner from the earth which forms those mists so commonly observed in marshy grounds. If a hole is

\* Watson's Chem. Essays, vol. iii. Ess. 2.

broken in ice, we may observe a mist rise from it; the water being warmer than the air, emits a vapour, which the cold condenses and renders visible. It is the same vapour which, when condensed by the cold of the night, forms the dew which is observed in small globules, like pearls, upon the leaves of plants\*. When the weather has been intensely cold, if a thaw suddenly comes on, the walls of houses are all covered with dew; for these thawing winds, coming from a hotter part of the world, bring with them a quantity of vapour, which is condensed by the cold substances, when it comes into a more northern climate.

\* This beautiful appearance has not escaped the poets; the Hebrew poets in particular have made the best advantage of the beauties of nature. The following is Buchanan's paraphrase of a part of the cxxxiii Psalm.

“ Ut aura suavis balsami, quum funditur  
 Aaronis in sacrum caput,  
 Et imbre læto proluens barbam & sinus  
 Limbum pererrat aureum:  
 Ut ros, tenella gemmulis argentiis  
 Pingens Sionis gramina;  
 Aut verna dulci inebrians uligine  
 Hermonis intonsi juga.”

Sweet as the od'rous balsam pour'd  
 On Aaron's sacred head;  
 Which o'er his beard and down his breast  
 A breathing fragrance shed.  
 As morning dew on Sion's mount  
 Beams forth a *silver* ray;  
 Or *studs with gems* the verdant pomp  
 That Hermon's tops display.

Variotm

Various theories have been proposed to account for the ascent of vapour. One of the most plausible is that which attributes it to the attraction of the air; but this theory is in a great measure destroyed, by the consideration that vapour will ascend in vacuo. The electric fire has also been called in to account for this phenomenon; but if the electric fire is no other than common fire, or some particular modification of it, there is no reason to believe that the spontaneous evaporation depends upon any other principle than that which has been already stated as the cause of the formation of common vapour from boiling water.

The fact appears to be, that there exists such an attraction between the particles of fire and those of water, that whenever a portion of the former in a disengaged state meets with any of the latter, they immediately unite. Hence, when water is heated beyond the temperature of the atmosphere, it naturally yields up a quantity of its superfluous fire to restore the equilibrium, and this fire always carries with it a quantity of the fluid medium in the form of vapour. When these vapours first ascend, they are in an invisible state; and they must be in some degree condensed to enable them to reflect the solar rays, so as to become visible. This frequently takes place when they reach the higher and colder regions of the atmosphere, or if they happen to meet with cold winds in their progress thither: they then appear to us in the form of clouds. A still greater degree of condensation renders them too heavy to be

be supported by the atmosphere, and they fall down in the form of rain, snow, or hail, according to the circumstances of their dissolution.

Agreeable to this theory is the common observation, that in very cold weather vapour becomes visible almost as soon as it is formed; thus in frost the breath, which is vapour from the lungs, is always visible. M. de Maupertuis saw in Lapland the warm vapour of a room converted into snow upon opening the door to the external air; and in a crowded assembly at Petersburg, the company suffering from the closeness of the room, a gentleman broke a window for relief; the consequence of which was, that the cold air rushing in, caused a visible circumagitation of a white snowy substance\*.

Agreeably also to the same principles it is evident that air is a fluid which has a stronger attraction for the matter of fire than water, but that by means of this insensible evaporation the interstices of the air, if I may so express myself, are filled with a quantity of vapour, which being extremely rare, and being equally diffused, is invisible to us. If, however, a stream of cold air is introduced from any quarter, the caloric, which is united with the water in the form of vapour, will flow into the cold air to restore the equilibrium, and the vapour will be condensed. The condensation will sometimes be only

\* Edin. Phil. Tr. Vol. I. p. 48.

“ Like words congeal’d in northern air.”

HUDIBRAS.

sufficient

sufficient to produce the appearance of clouds, but at some times it will be sufficient to cause rain, which will fall in greater or lesser quantities, in proportion to the quantity of moisture in the atmosphere, and the degree of cold in the condensing medium.



## CHAP. VI.

### OF IGNITION AND COMBUSTION.

*Ignition, what ; how produced.—Burning of Phosphorus.—Inflammable Air.—Culinary Fires.—Lamps, &c.—Why Flame ascends.—Theory of Argand's Lamp.—Best Form of Grates, Stoves, &c.—Combustion produced by some Substances without a Communication with the Atmosphere.—Gun-powder, &c.—Iron made to burn like a Candle.—Spontaneous Ignition.—Curious Facts.—Quantity of Heat excited in fusing different Bodies.—Scale of Heat.*

**I**GNITION is that state of bodies in which the matter of fire or caloric is rendered active, and obvious to the sight, by the emission of light; in other words, when both light and heat are at once emitted by any body, it is said to be ignited. Ignition does not imply combustion, as the latter indicates a change or dissolution of texture in the inflammable body; whereas some of the metals, and many of the earths, may be ignited without being consumed.—But this is a subject which it will be necessary to treat more at large when I come to speak of inflammable substances.

In all cases of ignition or inflammation the matter of fire is detached from some body in which it previously existed in a latent state. The substance with which fire is most copiously combined, and  
from

from which it is most easily detached, is *air*. If therefore any substance can be found in nature which has a greater attraction for the base of air than that has for the matter of fire, the union of these two substances, will detach a quantity of the fire which had existed in a latent or combined state; and ignition, and combustion, will be produced. Of this nature is the matter of phosphorus, and that very common or almost universal substance, which is distinguished by the name of hydrogen, or inflammable air. Thus if a quantity of phosphorus is exposed to the atmosphere, it will absorb a considerable quantity of the pure part of the air, and by the union be converted into phosphoric acid. In the mean time the fire will be detached from the air; and, provided the air is well charged with heat, ignition or accension will be produced on the surface of the phosphorus. Inflammable air (or bodies containing that principle) has, however, either a weaker attraction for air than phosphorus has, or its particles have a stronger attraction for each other. It is necessary therefore that it should be presented to the air in a rarer state; and a degree of internal agitation, and even a third attractive power, are required to effect the union of the two substances, and the detaching of the fire from them. Thus, for instance, if pure air is mixed with a quantity of inflammable air, the electric spark, or a small quantity of fire in some form or other, must be introduced to effect their accension. In this case a double attraction takes place.

place. The pure and inflammable airs unite together, or are condensed into a fluid, and the matter of fire, which is introduced, carries with it the fire which is detached from the two airs, and thus a complete ignition is produced. In the ordinary process of burning, when a quantity of inflammable or combustible substances are heaped together, and fire introduced among them, by the action of the fire the inflammable part is first expanded from its solid state into a state of inflammable vapour or air, it comes necessarily into contact with the pure air of the atmosphere, and the action of the fire still continuing, the matter of fire is detached from the air, and combustion ensues in the same manner as in the former case, when the pure and inflammable airs are fired by the electric spark.

Hence there can be no combustion without a supply of pure air; and from this consideration most of the phenomena of combustion may be explained. In a common coal fire, if the coals cake or adhere in such a manner that the inflammable part cannot come in contact with the external air, the fire is necessarily extinguished. Flame is ignited vapour; but as that part only which comes in contact with the air can be ignited, that part of the inflammable vapour, which is not consumed, takes the form of smoke and soot, and adheres to the side or top of the place or vessel which contains the fire. The flame of a common lamp or candle may be considered as a tube of fire, in the hollow of which the inflammable vapour is in-

closed. It assumes a conical form, in consequence of the gradual consumption of the vapour, which is lessened in quantity as it rises, and consequently is contracted in its dimensions. A considerable quantity of the vapour, however, still escapes in the form of smoke, as must be evident to any observer, and as is decidedly evinced by holding a paper, or any other covering, over the flame, in which case a quantity of soot will presently be collected.

If these principles are clearly understood, it will no longer be a subject of wonder that all flame naturally ascends. Vapour is considerably lighter than air, and flame is no other than ignited vapour. Thus in lighting a common lamp or candle at an ignited bar of iron, or any other burning body, the wick of the candle must be applied to the lower surface of the ignited body, and not held above it, because then the vapour, which the heat extracts from the candle, comes in contact with the burning body, and accension takes place. It sometimes indeed may happen, that the lamp or candle may be lighted by holding it above the ignited bar; but it is obvious, in that case, that a quantity of the oil or tallow first drops on the burning body, and is then converted into vapour and flame, so that at the time of the accension taking place, the wick is actually surrounded with flame, above as well as below.

To remedy the immense waste of oil, which, according to the common construction of lamps, was disposed of, unconsumed, in the form of smoke  
and

and foot, was the great object of that very ingenious invention, the patent lamp of M. Argand. I recollect, some years previous to M. Argand's invention, I turned my attention to the procuring of a vivid flame, without a waste of oil, or the offensiveness of smoke. I observed that, the smaller the wick of a lamp, the brighter in general was the flame, and for this plain reason, that in these cases a greater surface than usual, proportionably to the quantity of vapour, was exposed to the air. My scheme was, therefore, to procure a lamp with a number of very small wicks, between each of which there was to have been an orifice or chimney, which might introduce a current of air, and keep the flame proceeding from each wick distinct. M. Argand's, I must confess, is a great improvement upon this idea. By means of a thin circular wick, through the middle of which a current of air is introduced by a funnel, he produces a very thin flame, and consequently exposes a very large surface of the oily vapour to the contact of the air. As there is, however, a strong attraction between the particles of fire, there would be danger of the flame uniting from all the sides of the lamp, at a certain height above the funnel, and so forming a conical flame like that of a common candle, was it not that this effect is prevented by a tube of glass, with which he surrounds the flame, which, when warmed, counteracts the attraction, which the different sides of the circular flame would have for each other, and

so preserves the current of air free, and without interruption.

The same principles will apply to the construction of common fires. The great object should be, to expose as large a surface of the fuel as possible to the air, or rather, if possible, to introduce a strong and diffused current of air through the fire. On this principle the air furnace is constructed. It is well known that these furnaces consist of an aperture or ash-hole under the fire, and a high vent, funnel, or chimney above, and that the door, by which the fuel is introduced, is kept closed, unless it should be occasionally opened for the purpose of diminishing the heat. By means, therefore, of the high vent or funnel, the air above is rarefied and rendered lighter, and consequently the air below presses in through the ash pit; and if the bottom of the grate is kept clear, a strong current of air circulates directly through the fire, and supplies it constantly with this necessary ingredient. On similar principles the register stoves are constructed. In these the vent or chimney coming very near the grate, the air below it is forced through the fuel, and by enlarging or contracting the vent, the current of air is increased or diminished. The bath and pantheon stoves are also found to produce more heat in proportion to the quantity of fuel than common open grates, because they are usually set high, and the ash-pit or aperture below being closed on three sides, a considerable part of the air which enters

enters it is forced up through the fire. The same reasons will also satisfactorily account for the effects of a common bellows, which brings a supply of pure air to unite with the inflammable matter contained in the coal.

The inflammable and pure air, which are apparently consumed by the process of combustion, are in reality, by their union, converted into water, as will be evinced by fixing an alembic head, or any good recipient, to the top of Mr. Argand's lamp, in which a quantity of water will presently be found, but no foot.

There are, however, certain substances, such as gunpowder, &c. which will burn though the air of our atmosphere should be excluded, as in the receiver of an air-pump, when the air has been exhausted. To explain this, it must be premised, that nitre, or some of the ingredients of such compositions, contains a large quantity of the basis of pure air; and it must be remembered, that air consists of a certain matter or basis, which is expanded by a union with the matter or element of fire, but which is also capable of existing in a more condensed state. Let it also be remembered, that though air, which is a compound body, will not penetrate glass, yet the element of fire, or heat, will penetrate glass or any other substance with which we are acquainted. One of the ingredients of air, therefore, is contained in the nitre or gunpowder, and the other (the fire or heat) cannot be excluded. When therefore the matter or elementary part of

the air, is set free from the nitre by accension, it immediately meets with the matter of heat or fire, and becomes embodied into the form of air, and thus an actual supply of that material is generated, though the air of the atmosphere is totally excluded \*.

• According

\* Gunpowder is a mixture, which in an hundred parts contains about 75 of nitre,  $9\frac{1}{2}$  of sulphur, and  $15\frac{1}{2}$  of charcoal. The effects of gunpowder depend on the sudden production of a quantity of air, which takes place from the decomposition of the nitre. Nitre is composed of a fixed alkali and of nitrous acid, which is itself a compound of the bases of azote and oxygen. The ingredient first inflamed is the sulphur, which sets fire to the charcoal. The nitre is equally dispersed among all the particles of combustible matter, and as its quantity is by much the greatest, each particle of sulphur and charcoal is surrounded with nitre. When combustion, therefore, is once excited in the mass, the oxygen afforded by the nitre carries it on with great rapidity. The oxygen, being withdrawn from the azote, causes it to assume an aeriform state, and by being attracted by the charcoal converts the latter into fixable air. The sulphur also attracting some of the oxygen, but not sufficient to reduce it to the state of a fluid, is partly converted into volatile vitriolic acid, the smell of which is very perceptible. The gunpowder, therefore, is in an instant converted into three kinds of air, which occupy the space of the solid matter. What remains after combustion is a liver of sulphur formed by the union of some portion of that substance with the fixed alkali of the nitre.

The effects, however, of this mixture of nitre, sulphur, and coal, are trifling, in comparison with those of another preparation called fulminating powder. This is made by triturating in a hot marble mortar, with a wooden pestle, three ounces of nitre, two ounces of very dry fixed salt of tartar, and one ounce  
of



According to the different properties of bodies, they are more or less easily disposed to ignition. Iron is ignited with great difficulty; on the contrary,

of flowers of sulphur, till the whole is very accurately mixed. If a drachm of this powder is exposed to a gentle heat, in an iron ladle, it melts, and soon after produces a detonation as loud as the report of a cannon. ' This phenomenon, which is so much the more astonishing, because its effect is produced without inclosing the powder in any instrument, as is done with gunpowder, may be explained, by observing, 1. That it does not succeed, but by gradually heating the mixture, so as to melt it. 2. That if fulminating powder is thrown on ignited charcoal, it only detonates like nitre, but with very little noise. 3. That a mixture of liver of sulphur with nitre, in the proportion of one part of the former, and two of the latter, fulminates with more rapidity, and produces as loud a report as the composition of sulphur, nitre, and alkali: hence it appears, that when fulminating powder is heated, liver of sulphur is formed before the detonation takes place; and this fact is sufficient to explain the whole appearance. When crystallized nitre and liver of sulphur are exposed to the action of heat, inflammable or hepatic gas is disengaged from the latter, while the salt gives out vital air. Now these two, which together are capable of producing a strong inflammation, as we have observed in the history of inflammable gas, are set on fire by a portion of the sulphur. But as the thick fluid they are obliged to pass through presents a considerable obstacle, and as the whole takes fire at the same instant, they strike the air with such rapidity, that it resists in the same manner as the chamber of a musquet resists the expansion of gunpowder. A proof of this is observable in the effect the fulminating powder has on the ladle in which it explodes. The bottom of this vessel is bulged outwards, and the sides bent inwards, in the same manner as if it had been acted on by a force directed perpendicularly downwards, and laterally inwards.'—*Fourcroy's Chem.* v. ii. p. 388.

trary, not only the phosphorus of Kunkel, but the pyrophori, which are made of three parts of flour, or any vegetable matter convertible into charcoal, and one of alum, will immediately ignite, on being exposed to the air in the ordinary heat of our atmosphere. In this case the pyrophorus, which consists of a light spongy texture, presents a large surface containing a quantity of inflammable matter to the atmosphere, and the union of the two substances immediately succeeding, the matter of fire is emitted, and ignition takes place.

Every means, indeed, by which pure air may be attracted and condensed, will produce flame. It was observed in the preceding paragraph, that iron was ignited with difficulty; yet if a very small iron wire is conveyed into a close bottle filled with this air, with a small piece of tinder or any combustible matter upon it, to which fire has been communicated, the wire will be observed to burn, after the other combustible matter is consumed, with a clear and bright flame, and if there is a large quantity of pure air, the whole of the iron will be converted into a calx.

Gold precipitated from its solution in aqua regia by means of volatile alkali, constitutes a substance called fulminating gold, the effects of which are still more tremendous than those of the preceding compositions. An extremely small portion of it is sufficient to produce alarming, and even fatal effects; and what renders it still more dangerous is, that a mere blow, or a slight degree of friction, are sufficient to ignite it. With respect to the cause of the explosive power of this substance, it will be explained when I treat of gold itself.

It has been amply demonstrated, that the condensation, not only of pure air, but of every fluid, is attended with the emission of heat or elementary fire; and even the partial condensation of a fluid, or the reduction of it from a rarer to a denser state, will produce the same effect. Thus air and vapour are rarer fluids than water, and their condensation into water always produces sensible heat; thus fixable air is a denser fluid than atmospherical or pure air; and when a quantity of the latter is by any process converted into the former, a quantity of superfluous caloric is consequently emitted. This is the case in all fermenting bodies, which absorb a large quantity of the pure air of the atmosphere, and emit that dense acid fluid, which always hangs over their surface like a vapour, and is universally known by the name of fixable air: and this process is always attended with heat, that is, with the detaching of a quantity of elementary fire. The accension or ignition of the mass depends, however, on the speedy emission of the matter of fire, that is, upon the violence of attraction between the two substances which occasions the condensation. When sulphur, iron-filings, and water, are mixed together and kneaded up into a paste, the air is rapidly attracted, and the mass becomes spontaneously on fire. Hayricks and other fermenting masses are frequently fired by this kind of spontaneous process.

If one of the substances contains a large quantity of the basis of pure air, and a strong general attraction exists between the substances a similar effect will

will ensue. Thus, if aqua fortis or strong nitrous acid is poured upon oil of turpentine, the attraction between the inflammable part of the oil and the pure air, which the nitrous acid contains in abundance, will be so violent, that the whole will be instantaneously converted into flame. The same effect is produced from a mixture of black wad (an ore of manganese, containing much oxygen or pure air) with common-linseed oil. If a quantity of nitrated copper also, or the salt which is formed by the solution of copper in the nitrous acid, is moistened, and inclosed in a piece of tin-foil, the salt melts or deliquesces, nitrous fumes are emitted, and the mass suddenly bursts into a flame. This effect is undoubtedly occasioned by the strong attraction of the tin for the nitrous acid, by which the fire is extricated in so rapid a manner as to produce inflammation.

The effects of spontaneous inflammation are chiefly seen in the mineral world; and to this cause is to be attributed a variety of the most formidable phenomena of nature, such as volcanoes, earthquakes, &c.

M. Lavoisier describes an apparatus for ascertaining the quantities of heat extricated during the combustion of different substances. This contrivance rests on the proposition, that when a body is burnt in the center of a hollow sphere of ice, and supplied with air at the temperature of  $32^{\circ}$ , the quantity of ice melted from the inside of the sphere becomes a measure of the relative quantities of heat disengaged.

disengaged. With this apparatus, phosphorus, charcoal, and hydrogen gas, gave the following results :

One pound of phosphorus melted one hundred pounds of ice.

One pound of charcoal melted ninety-six pounds eight ounces.

One pound of hydrogen gas melted 295 lbs. 9 ounces,  $3\frac{1}{2}$  drams.

As a concrete acid is formed by the combustion of phosphorus, it is probable that very little heat or caloric remains in the acid, and, consequently, that the above experiment gives us very nearly the whole quantity of elementary fire contained in the oxygen gas.

M. Lavoisier had found, by a former experiment, that one pound of phosphorus absorbs one pound eight ounces of oxygen during combustion ; and since, by the same operation, one hundred pounds of ice are melted, it follows, that the quantity of caloric contained in one pound of oxygen gas is capable of melting 66 lbs. 10 ounces, 5 drams, 24 grains of ice. By the help of this simple contrivance for measuring quantities of heat, M. Lavoisier has been able to arrive at the following conclusions ;

‘ From the combustion of phosphorus, as related in the foregoing experiments, it appears, that one pound of phosphorus requires 1 lb. 8 oz. of oxygen gas for its combustion, and that 2 lbs. 8 oz. of concrete phosphoric acid are produced.

‘ The

‘ The quantity of caloric disengaged by the combustion of one pound of phosphorus, expressed by the number of pounds of ice melted during that operation, is       —       —       —       100.00000.

The quantity disengaged from each pound of oxygen, during the combustion of phosphorus, expressed in the same manner, is       —       66.66667.

The quantity disengaged during the formation of one pound of phosphoric acid, 40.00000. The quantity remaining in each pound of phosphoric acid,       —       —       —       —       0.00000\*.

In the combustion of one pound of charcoal, 2 lbs. 9 oz. 1 gros 10 grs of oxygen gas are absorbed, and 3 lbs. 9 oz. 1 gros 10 grs. of carbonic acid gas are formed.

Caloric, disengaged during the combustion of one pound of charcoal,       —       —       96.50000†.

Caloric disengaged during the combustion of charcoal, from each pound of oxygen gas absorbed,       —       —       —       —       —       37.52823.

Caloric disengaged during the formation of one pound of carbonic acid gas,       —       27.02024.

\* We here suppose the phosphoric acid not to contain any caloric, which is not strictly true; but, as I have before observed, the quantity it really contains is probably very small, and we have not given it a value, for want of a sufficient data to go upon.

† All these relative quantities of caloric are expressed by the number of pounds of ice, and decimal parts, melted during the several operations.

Caloric

Caloric retained by each pound of oxygen after the combustion — — — 29.13844.

Caloric necessary for supporting one pound of carbonic acid in the state of gas — 20.97960.

In the combustion of one pound of hydrogen gas, 5 lbs. 10 oz. 5 gros, 24 grs. of oxygen gas are absorbed, and 6 lbs. 10 oz. 5 gros 24 grs. of water are formed.

Caloric from each lb. of hydrogen gas — — — 295.58950.

Caloric from each lb. of oxygen gas, — — — 52.16280.

Caloric disengaged during the formation of each pound of water, 44.33840.

Caloric retained by each lb. of oxygen after combustion with hydrogen — — — 14.50386.

Caloric retained by each lb. of water at the temperature of Zero (32°) — — — 12.32823.

‘ When we combine nitrous gas with oxygen gas, so as to form nitric or nitrous acid, a degree of heat is produced, which is much less considerable than what is evolved during the other combinations of oxygen; whence it follows that oxygen, when it becomes fixed in nitric acid, retains a great part of the heat which it possessed in the state of gas. It is certainly possible to determine the quantity of caloric which is disengaged during the combination

tion of these two gasses, and consequently to determine what quantity remains after the combination takes place. The first of these quantities might be ascertained, by making the combination of the two gasses in an apparatus surrounded by ice; but, as the quantity of caloric disengaged is very inconsiderable, it would be necessary to operate upon a large quantity of the two gasses in a very troublesome and complicated apparatus. By this consideration, Mr. de la Place and I have hitherto been prevented from making the attempt. In the mean time, the place of such an experiment may be supplied by calculations, the results of which cannot be very far from truth.

‘ Mr. de la Place and I deflagrated a convenient quantity of nitre and charcoal in an ice apparatus, and found that twelve pounds of ice were melted by the deflagration of one pound of nitre. We shall see, in the sequel, that one pound of nitre is composed, as under, of

Pot-ash 7 oz. 6 gros 51.84 grs. = 4515.84 grs.

Dry acid 8 1 21.16 = 4700.16.

The above quantity of dry acid is composed of

Oxygen 6 oz. 3 gros 66.34 grs. = 3738.34 grs.

Azote 1 5 25.82 = 961.82.

‘ By this we find that, during the above deflagration, 2 gros  $1\frac{1}{3}$  gr. of charcoal have suffered combustion,



bustion, along with 3738.34 grs. or 6 oz. 3 gros 66.34 grs. of oxygen. Hence, since 12 lbs. of ice were melted during the combustion, it follows, that one pound of oxygen burnt in the same manner would have melted 29.58320 lbs of ice. To which the quantity of caloric, retained by a pound of oxygen after combining with charcoal to form carbonic acid gas, being added, which was already ascertained to be capable of melting 29.13844 lbs. of ice, we have for the total quantity of caloric remaining in a pound of oxygen, when combined with nitrous gas in the nitric acid 58.72164; which is the number of pounds of ice the caloric remaining in the oxygen in that state is capable of melting.

‘ We have before seen that, in the state of oxygen gas, it contained at least 66.66667; wherefore it follows that, in combining with azote to form nitric acid, it only loses 7.94502. Farther experiments upon this subject are necessary to ascertain how far the results of this calculation may agree with direct fact. This enormous quantity of caloric retained by oxygen in its combination into nitric acid, explains the cause of the great disengagement of caloric during the deflagrations of nitre; or, more strictly speaking, upon all occasions of the decomposition of nitric acid.

‘ Having examined several cases of simple combustion, I mean now to give a few examples of a more complex nature. One pound of wax-taper  
being

**144 Heat extricated by burning a Wax Taper. [Book II.**

being allowed to burn slowly in an ice apparatus, melted 133 lbs. 2 oz.  $5\frac{1}{2}$  gros of ice. According to my experiments in the Memoirs of the Academy for 1784, p. 606, one pound of wax-taper consists of 13 oz. 1 gros 23 grs. of charcoal, and 2 oz. 6 gros 49 grs. of hydrogen.

‘ By the foregoing experiments, the above quantity of charcoal ought to melt 79.39390 lbs. of ice; and the hydrogen should

melt	—	—	—	52.37605
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In all 131.76995 lbs.

‘ Thus, we see the quantity of caloric disengaged from a burning taper, is pretty exactly conformable to what was obtained by burning separately a quantity of charcoal and hydrogen, equal to what enters into its composition. These experiments with the taper were several times repeated, so that I have reason to believe them accurate \*.’

The following is a table of the different degrees of heat, which certain bodies exhibit in given circumstances, estimated according to Fahrenheit’s scale, and collected from different authors.

\* Lavoisier’s Chemistry.

A SCALE

## A SCALE OF HEAT.

The first part of this table is taken from Mr. Wedgwood's scale, according to his clay pyrometer.

	Fahr.	Wedg.
Extremity of the scale of Mr. Wedg-		
wood's thermometer — —	32277°	240°
Greatest heat of his small air furnace	21877	160
Cast-iron melts — —	17977	130
Greatest heat of a common smith's?		
forge — — —	17327	125
Welding heat of iron, greatest	13427	95
- - - - - , least	12777	90
Fine gold melts — —	5237	32
Fine silver melts — —	4717	28
Swedish copper melts — —	4587	27
Brass melts — —	3807	21
Heat by which his enamel colours		
are burnt on — —	1857	6

	Fahr.
Iron with a white sparkling heat —	2780°
Iron with a heat almost white —	2080
The heat of live coals without blowing,	
perhaps about — —	1650
Iron with a glowing red by day-light —	1600
Iron just red-hot by day-light —	1120
Iron just red-hot in the dark —	1000
Greatest heat of lead in fusion —	820
Colours of iron are burned off —	800

			Fahr.
Mercury boils, by some placed at 600	—	—	700°
Polished iron takes a full blue	—	—	700
Polished iron takes a purple	—	—	660
Linseed oil boils, by some at 600	—	—	620
Lead melts	—	—	610
Polished iron takes a straw colour	—	—	605
Oil of vitriol boils	—	—	540
Brass takes a blue colour	—	—	500
Bismuth melts	—	—	460
Tin-foil and bismuth melt	—	—	450
Tin melts	—	—	408
Equal parts of tin and bismuth melt	—	—	283
Equal parts of tin, lead, and bismuth melt	—	—	220
Water boils	—	—	212
Brandy boils	—	—	190
Rectified spirit of wine boils	—	—	175
Serum of blood and white of eggs coagulate	—	—	156
Bees-wax melts	—	—	142
Greatest heat of water which the hand can well bear	—	—	114
Heat of the Sirocco wind at Palermo, in Sicily	—	—	112
Violent feverish heat	—	—	108
Heat of the skin of ducks, geese, and pigeons	—	—	106
Heat of the skin of cats, dogs, sheep, &c.	—	—	103
Heat of the human body in health	—	—	98
Heat of a hive of bees	—	—	97
Sultry weather	—	—	75
Ordinary summer heat	—	—	65
			Water

	Fahr.
Water just freezing, or ice just melting —	32°
Milk freezes — — —	30
Vinegar of ordinary strength froze at —	27
Strong wines froze at — —	20
A mixture of snow and salt sinks the thermometer to — — —	0
Greatest natural cold observed in England	3
Weak spirit of wine froze — —	33
Mercury freezes about — —	39

As mercury contracts irregularly on freezing, no cold below this can be observed by the thermometers now in use.

## B O O K   I I I.

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### C H A P.   I.

#### HISTORY OF DISCOVERIES CONCERNING LIGHT, &c.

*Opinions of the Platonics.—Of Aristotle.—Of Alhazen.—Of Roger Bacon.—The Invention of Spectacles.—Treatise of Maurolycus on Vision.—Long and short Vision.—Reason that the Sun's Image appears round, though the Rays pass through an angular Aperture.—Invention of the Camera Obscura.—Conjectures of Fletcher on the Rainbow.—Invention of the Telescope.—Supposed to be by Zacharias Jansen.—Galileo.—Kepler.—Invention of the Microscope.—Tycho Brahe.—Reformation of distorted Images.—Snellius and Hortensius.—Descartes.—Scheiner.—Velocity of Light discovered.—Boyle's Discoveries on Colours.—Grimaldi.—Gregory.—Newton; his Discoveries on Colours.—On Refrangibility.—Bolognian Stone.—Baldwin's Phosphorus, &c.—Bradley.—Bouguer.—Melville.—Dolland.—De la Motte.—Delaval.*

**T**HE most ancient hypothesis, which leads to the true theory of light and colours, is that of the Platonics, namely, that light, from whatever it proceeds, is propagated in right lines; and that when it is reflected from the surfaces of polished bodies, the angle of incidence is equal to the angle of

of

of reflexion. To this may be added the opinion of Aristotle, who supposed that rainbows, halos, and mock suns, were occasioned by the reflexion of the sun beams in different circumstances. We have reason to believe, that the use of convex glasses, both as magnifiers and as burning glasses, was not unknown to the ancients, though the theory was not understood. The magnifying power of glasses, and some other optical phenomena, were also largely treated of by Alhazen, an Arabic philosopher of the twelfth century. These observations were followed by those of Roger Bacon, who demonstrates by actual experiment, that a small segment of a glass globe would greatly assist the sight of old persons; and from the hints afforded by these two philosophers, it is not unreasonable to conclude, that the invention of spectacles proceeded. Concerning the actual author of this useful invention, we have no certain information; we only find, that it was generally known about the beginning of the fourteenth century.

In the year 1575, Maurolycus, a teacher of mathematics at Messina, published a treatise on optics, in which he demonstrates, that the crystalline humour of the eye is a lens, which collects the rays of light proceeding from external objects, and throws them on the retina, or optic nerve. From this principle he was led to discover the reason of what is called short and imperfect sight. In the one case, the rays converge too soon; in the other, they do not converge soon enough. Hence short-sighted persons

sons are relieved by a concave glass, which causes the rays to diverge in some degree before they enter the eye, and renders it more difficult for them to converge so fast as they would have done after entering the crystalline humour; hence, too, he proves, that a convex lens is of use to persons who have weak, but long sight, by causing the rays to converge sooner, and in a greater quantity, than would otherwise happen. He was the first, also, that solved a problem, which had caused much perplexity in the ancient schools, respecting the sun's image appearing round, though the rays that form it are transmitted into a dark room through an angular aperture. He considered, that as the rays of light are constantly proceeding, in every direction, from every part of the sun's disk, "they must be crossing each other from the extreme part of it in every point of the aperture; so that every such point will be the apex of two cones, of which the base of the one is the sun's disk, and that of the other his image on the opposite wall." The whole image, therefore, consists of a number of images, all of which are circular; the image of the sun formed of those images must be circular also; and it will approach the nearer a perfect circle, the smaller the aperture, and the more distant the image.

Nearly about the same time, Johannes Baptista Porta, of Naples, invented the camera obscura; and his experiments upon that instrument convinced him that light is a body, by the intromission of which into the eye vision is performed; for it ought to



to be remarked, that before his time the opinion was pretty general, that vision depended upon what was termed *visual rays*, proceeding from the eye. In this the system of Porta corresponds nearly with that of Maurolycus; but it ought to be remarked, that the discoveries of each of these two philosophers were unknown to the other. He shews, moreover, that a defect of light is remedied by the dilatation of the pupil, which contracts involuntarily when exposed to a strong light, and opens when the light is faint and languid.

One Fletcher, of Breslau, in 1571, endeavoured to account for the phenomena of the rainbow, by a double reflexion and one refraction; but Antonio de Dominis, whose treatise was published in 1611, was the first who came near to the true theory. He describes the progress of the ray of light through each drop of the falling rain; he shews that it enters the upper part of the drop, where it suffers one refraction; that it is reflected once, and then refracted again, so as to come directly to the eye of the spectator; why this refraction should produce the different colours was reserved for Sir I. Newton to explain.

The latter end of the sixteenth century was illustrious for the invention of telescopes. It is generally allowed to have been casual. That effect of refraction, which causes the rays of light, in passing through a dense medium thicker in the middle, to converge to a point, and also that which takes place

when they pass through one thicker at the extremities, had been long observed; and the assistance which convex and concave glasses afforded to the sight had brought them into common use. The inventor of the telescope is not certainly known. The most probable account is, that one Zacharias Jansen, a spectacle maker of Middleburgh, trying the effect of a concave and convex glass united, found that, placed at a certain distance from each other, they had the property of bringing distant objects apparently nearer to the eye. Telescopes were greatly improved by Galileo, who made one to magnify thirty-three times, and with this he made all his wonderful astronomical discoveries.

The rationale of telescopes was, however, not explained till Kepler, who described the nature and the degree of refraction, when light passed through denser or rarer mediums, the surfaces of which are convex or concave, namely, that it corresponds to the diameter of the circle of which the convexity or concavity are portions of arches. He suggested some improvements in the construction of telescopes, which, however, were left to others to put in practice.

To the Jansens we are also indebted for the discovery of the microscope; an instrument depending upon exactly the same principles as the former. In fact, it is not improbable that the double lens was first applied to the observation of near but minute objects, and afterwards, on the same principles, to  
objects

objects which appeared minute on account of their distance.

Much attention was given by Kepler to the investigation of the law of refraction; but he was able to advance no nearer the truth than the observation, that when the incident ray does not make an angle of more than thirty degrees with the perpendicular, the refracted ray proceeds in an angle which is about two-thirds of it. Many disputes arose about the time of Kepler (1600) upon this subject, but it appears that little was effected by them in the cause of truth.

Kepler was more successful in pursuing the discoveries of Maurolycus and B. Porta. He demonstrated that images of external objects were formed upon the optic nerve by the foci of rays coming from every part of the object; he also observed, that these images are inverted; but this circumstance, he says, is rectified by the mind, which, when an impression is made on the lower part of the retina, considers it as made by rays proceeding from the higher parts of the object. Habit is supposed to reconcile us to this deception, and to teach us to direct our hands to those parts of objects from which the rays proceed. Tycho Brahe, observing the apparent diminution of the moon's disk in solar eclipses, imagined that there was a real diminution of the disk by the force of the sun's rays; but Kepler said, that the disk of the moon does not appear less in consequence of being unenlightened, but rather that it appears at other times

times larger than it really is, in consequence of its being enlightened. For pencils of rays from such distant objects generally come to their foci before they reach the retina, and consequently diverge and spread when they reach it. For this reason, he adds; different persons may imagine the disk to be of different magnitudes, according to the relative goodness of their sight.

In the sixteenth century also many improvements were made in perspective; the ingenious device, in particular, of the reformation of distorted images by concave or convex speculums was invented, but it is uncertain by whom.

The true law of refraction was discovered by Snellius, the mathematical professor at Leyden; but not living to complete it, the discovery was published and explained by Professor Horrensius. Some discoveries of lesser importance were made at this time, among others by Descartes, who very clearly explained the nature and cause of the figure of the rainbow, though he was able to give no account of the colours; he however considered the small portion of water, at which the ray issues, as having the effect of a prism, which was known to have the property of rendering the light, which was transmitted through it, coloured.

In 1625, the curious discovery of Scheiner was exhibited at Rome, which ascertains the fact, that vision depends upon the images of external objects upon the retina. For taking the eye of an animal, and cutting away the coats of the back part, and presenting

presenting different objects before it, he displayed their images distinctly painted on the naked retina or optic nerve. The same philosopher demonstrated by experiment, that the pupil of the eye is enlarged in order to view remote objects, and contracted when we view those which are near. He shewed, that the rays proceeding from any object, and passing through a small hole in a pasteboard, cross one another before they enter the eye; for if the edge of a knife is held on the side next the eye, and is moved along till it in part covers the hole, it will first conceal from the eye that part of the object which is situated on the opposite side of the hole.

Towards the middle of the seventeenth century the velocity of light was discovered by some members of the Royal Academy of Sciences at Paris, particularly Casini and Roemer, by observing the eclipses of Jupiter's satellites. About the same time Mr. Boyle made his experiments on colours. He proved that snow did not affect the eye by a native but reflected light, a circumstance which, however, at this day, we should scarcely believe was ever necessary to be proved by experiment. By admitting also a ray of light into a dark room, and letting it fall on a sheet of paper, he demonstrated, that white reflected much more light than any other colour; and to prove that white bodies reflect the rays outwards, he adds, that common burning-glasses will not, for a long while, burn or discolour white paper; on the contrary, a concave mirror of black marble did not reflect the rays of the sun with near so much power

power as a common concave mirror. The same effect was verified by a tile, one half of the surface of which was white, and the other black.

Some experiments were made about this time on the difference of the refractive powers of bodies; and the first advance to the great discoveries by means of the prism was made by Grimaldi, who observed, that a beam of the sun's light, transmitted through a prism, instead of appearing round on the opposite wall, exhibited an oblong image of the sun. Towards the close of this century the reflecting telescope was invented by our countryman James Gregory.

The reader will soon perceive how very imperfect all the preceding discoveries were in comparison with those of Sir I. Newton. Before his time, little or nothing was known concerning colours; even the remark of Grimaldi respecting the oblong figure of the sun, made by transmitting the rays through a prism, was unknown to our great philosopher, having been published only the year before. This, however, it appears, was the first circumstance which directed the attention of Newton to the investigation of the theory of colours. Upon measuring the coloured image, which was made by the light admitted into a dark chamber through a prism, he found that its length was five times greater than its breadth. So unaccountable a circumstance induced him to try the effect of two prisms; and he found that the light, which by the first prism was diffused into an oblong, was by the  
second

second reduced to a circular form, as regularly as if it had passed through neither of them. After many conjectures and experiments relating to the cause of these phenomena, he at length applied to them what he calls the *experimentum crucis*. He took two boards, and placed one of them close to the window, so that the light might be admitted through a small hole made in it, and after passing through a prism might fall on the other board, which was placed at about twelve feet distance, and in which there was also a small aperture, in order that some of the incident light might pass through it. Behind this hole, in the second board, he also placed a prism, so that the light, after passing both the boards, might suffer a second refraction before it reached the wall. He then moved the first prism in such a manner as to make the several parts of the image cast upon the second board pass successively through the hole in it, that he might observe to what places on the wall the second prism would refract them. The consequence was, that the coloured light, which formed one end of the image, suffered a refraction considerably greater than that at the other end; in other words, rays of light of one colour were more refrangible than those of another. The true cause, therefore, of the length of the image was evident, since it was proved by the experiment, that light was not homogenous, but consisted of different particles or rays, which were capable of different degrees of refrangibility, and according to which they are transmitted through the prism

prism to the opposite wall. It was further evident from these experiments, that as the rays of light differ in refrangibility, so they also differ in exhibiting particular colours, some rays producing the colour red, others that of yellow, blue, &c. and of these different-coloured rays, separated by means of the prism according to their different degrees of refrangibility, the oblong figure on the wall was composed. But to relate the great variety of experiments, by which he demonstrated these principles, or the extensive application of them, would lead me too much into detail; let it suffice to say, that he applied his principles to the satisfactory explanation of the colours of natural bodies, of the rainbow, and of most of the phenomena of nature, where light and colour are concerned; and that almost every thing which we at present know upon these subjects was laid open by his experiments.

His observations on the different refractive powers of different substances are curious and profound; but chemistry was at that period scarcely in a state sufficiently advanced to warrant all his conclusions. The general result is, that all bodies seem to have their refractive powers proportional to their densities, excepting so far as they partake more or less of sulphureous or oily particles.

The discovery of the different refrangibility of the component rays of light suggested defects in the construction of telescopes, which were before unthought of, and in the creative hand of a Newton led to some no less extraordinary improvements in them.



them. It is evident, that since the rays of light are of different refrangibilities, the more refrangible will converge to a focus much sooner than the less refrangible, consequently that the whole beam cannot be brought to a focus in any one point, so that the focus of every object-glass will be a circular space of considerable diameter, namely, about one fifty-fifth of the aperture of the telescope. To remedy this, he adopted Gregory's idea of a reflector, with such improvements as have been the basis of all the present instruments of this kind.

When a science has been carried to a certain degree of perfection, subsequent discoveries are too apt to be considered as of little importance. The real philosopher will not, however, regard the discoveries on light and colours, since the time of Newton, as unworthy his attention. By a mere accident, a very extraordinary property in some bodies of imbibing light, and afterwards emitting it in the dark, was observed. A shoemaker of Bologna, being in quest of some chemical secret, calcined, among other things, some stones of a particular kind, which he found at the bottom of Mount Peterus, and casually observed, that when these stones were carried into a dark place after having been exposed to the light, they possessed a self-illuminating power. Accident afterwards discovered the same property in other substances. Baldwin of Misnia, dissolving chalk in aqua-fortis, found that the residuum, after distillation, exactly resembled the Bolognian stone in retaining and  
emitting

emitting light, whence it now has the name of Baldwin's phosphorus; and M. Du Fay observed the same property in all substances that could be reduced to a calx by burning only, or after solution in nitrous acid. These facts seem to establish the materiality of light.

Some very accurate calculations were made about the year 1725 by Dr. Bradley, which afforded a more convincing proof of the velocity of light, and the motion of the earth in its orbit. Nor must we forget M. Bouguer's very curious and accurate experiments for ascertaining the quantity of light which was lost by reflexion, the most decisive of which was by admitting into a darkened chamber two rays of light, one of which he contrived should be reflected, and the other fall direct on the opposite wall; then by comparing the size of the apertures, by which the light was admitted (that through which the direct ray proceeded being much smaller than that through which the reflected ray was suffered to pass, and the illumination on the wall being equal in both) he was enabled to form an exact estimate of the quantity of light which was lost. To prove the same effect with candles, he placed himself in a room perfectly dark, with a book in his hand, and having a candle lighted in the next room, he had it brought nearer to him till he could just see the letters, which were then twenty-four feet from the candle. He then received the light of the candle reflected by a looking-glass upon the book, and he found the whole distance of the book from the source

source of the light (including the distance from the book to the looking-glass) to be only fifteen feet; whence he concluded, that the quantity of direct light is to that of reflected as 576 to 225; and similar methods were pursued by him for measuring the proportions of light in general \*.

The speculations of Mr. Melville, concerning the blue shadows which appear from opake bodies in the morning and evening, when the atmosphere is serene, are far from uninteresting. These phenomena he attributes to the power which the atmosphere possesses of reflecting the fainter and more refrangible rays of light, the blue, violet, &c. and upon this principle he also explained the blue colour of the sky, and some other phenomena.

The same period produced Mr. Dollond's great improvement in the construction of telescopes. It consists in using three glasses of different refractive powers, crown and flint glass, which correct each other. The great dispersion of the rays which the flint-glass produces, is the effect of the lead, and is in proportion to the quantity of that metal, which is used in its composition. Mr. Martin found the refractive powers of different glasses to be in proportion to their specific gravity.

Several discoveries and improvements have been made since the time of Newton in that branch of optics which relates more immediately to vision;

\* See an accurate description of M. Bouguer's instruments, Priestley's *Hist. of Optics*, Per. vi. s. 7.

but these, being rather foreign to the chief subject of this chapter, I shall not detail. One discovery only I shall mention, because it not only is curious in itself, but because it led to the explanation of several circumstances relating to vision. M. De la Motte, a physician of Dantzick, was endeavouring to verify an experiment of Scheiner, in which a distant object appeared multiplied when viewed through several holes made with the point of a pin in a card, not further distant from one another than the diameter of the pupil of the eye; but notwithstanding all his labour, he was unable to succeed, till a friend happening to call upon him, he desired him to make the trial, and it answered perfectly. This friend was short-sighted; and when he applied a concave glass close to the card, the object, which seemed multiplied before, now appeared but one.

The last, though not least successful adventurer in this branch of science, is Mr. Delaval, who, in a paper read before the Philosophical Society of Manchester in 1784, has endeavoured, with great ingenuity, to explain the permanent colours of opaque bodies. The majority of those philosophers, who have treated of light and colours, have, he observes, supposed that certain bodies or surfaces reflected only one kind of rays, and therefore exhibited the phenomena of colours; on the contrary, Mr. Delaval, by a variety of well conducted experiments, evinced, that colours are exhibited, not by reflected, but by transmitted light. This he proved by covering coloured glasses and other  
transparent

transparent coloured media, on the further surface; with some substance perfectly opake, when he found they reflected no colour, but appeared perfectly black. He concludes, therefore, as the fibres or bases of all vegetable, mineral, and animal substances are found, when cleared of heterogeneous matters, to be perfectly *white*, that the rays of light are in fact reflected from these white particles, through coloured media, with which they are covered; that these media serve to intercept and impede certain rays in their passage through them, while, a free passage being left to others, they exhibit, according to these circumstances, different colours. This he illustrates by the fact remarked by Dr. Halley, who, in diving deep into the sea, found that the upper part of his hand, when extended into the water from the diving bell, reflected a 'deep red colour, while the under part appeared perfectly green. The conclusion is, that the more refrangible rays were intercepted and reflected by particles contained in the sea-water, and were consequently reflected back by the under part of the hand; while the red rays, which were permitted to pass through the water, were in the same manner reflected by the upper part of the hand, which therefore appeared of a red rose colour. Those media, our author thinks, transmit coloured light with the greatest strength which have the strongest refractive power.

## CHAP. II.

## OF THE NATURE OF LIGHT.

*Various Opinions on the Action of Light.—Theory of a vibrating Medium; supported by Descartes, &c.—Objections to this Theory.—Light consists of infinitely minute Particles projected from the luminous Body.—Inquiry respecting the Identity of Light and Fire.—Experiments of Mr. Boyle.—Why Light is not always accompanied with Heat.—Velocity of Light.—Light always moves in Right Lines.—Rarity of Light.—Force or Momentum of Light.—Mitchell's Experiment.—Inquiry how far the Sun's Magnitude is diminished by the Emission of Light.—Light subject to the ordinary Laws of Nature.—Light attracted by the Bolognian Phosphori.—The same Property in Diamonds, and other Precious Stones.—Refraction of Light.—Reflexion.—Theory of Colours.*

**N**UMEROUS opinions have successively been adopted concerning this wonderful fluid. It has been sometimes considered as a distinct substance, sometimes as a quality, sometimes as a cause, frequently as an effect; by some regarded as a compound, and by others as a simple substance. Des Cartes and other philosophers of high repute have imagined that the sensation which we receive from light is to be attributed entirely to the vibrations of a subtile medium, or fluid, which is diffused throughout the universe, and which is put into action by the impulse of the sun. In this view they consider

consider light as analogous to sound, which is known to depend entirely on the pulsations of the air upon the auditory nerves; and in support of this opinion, it has been even lately urged\*, 1st. That some diamonds, on being rubbed or chafed, are luminous in the dark. 2d. That an electric spark, not larger, but much brighter, than the flame of a candle, may be produced, and yet that no part of the electric fluid is known to escape, in such a case, to distant places, but the whole proceeds in the direction to which it is destined by the hand of the operator. Weaker or stronger sparks of this fluid are also known to differ in colour; the strongest are white and the weakest red, &c.

To this opinion, however, there are many pressing and, indeed, insurmountable objections. 1st, The velocity of sound bears a very small proportion to that of light. Light travels, in the space of eight minutes, a distance in which sound could not be communicated in seventeen years; and even our senses may convince us, if we attend to the explosion of gunpowder, &c. of the almost infinite velocity of the one compared with that of the other. 2dly, If light depended altogether on the vibrations of a fluid, no solid reason can be assigned why this fluid should cease to vibrate in the night, since the sun must always affect some part of the circumambient fluid, and produce a perpetual day. 3dly, The

\* See Dr. Franklin's works; and Professor Boudoin's *Memoir. Transactions of American Academy*, Vol. i.

artifice of candles, lamps, &c. would be wholly unnecessary upon this hypothesis, since, by a quick motion of the hand, or of a machine contrived for this purpose, light might on all occasions be easily produced. 4thly, Would not a ray of light, admitted through a small aperture, put in motion, according to this theory, the whole fluid contained in a chamber. In fact, we know that light is propagated only in right lines, whereas sound, which depends upon vibration, is propagated in every direction. 5thly, The separation or extension of the rays, by means of the prism, can never be accounted for by the theory of a vibrating medium. 6thly, The texture of many bodies is actually changed by exposure to the light. The juice of a certain shell-fish contracts, it is well known, a very fine purple colour, when permitted to imbibe the rays of the sun; and the stronger the light is the more perfect the colour. Pieces of cloth wetted with this fluid become purple, even though inclosed in glass, if the solar light only is admitted; but the effect is totally excluded by the intervention of the thinnest plates of metal, which exclude the light. Some of the preparations of silver also, such as luna cornea, will remain perfectly white, if covered from the light, but contract a dark purple colour when exposed to it; and even the colour of plants is derived from the light, since a plant which vegetates in darkness will be perfectly white. As colour is imparted by light, so it is also destroyed by it. It must have fallen within the observation of every reader, that silks, and other stuffs

of



of delicate colours, are greatly affected by the action of light. Experiments have been made upon the same stuffs by exposing them to both heat and moisture in the dark, and also by exposing them to the light in the vacuum of an air pump, and it was found by all these experiments, that the change of colour was to be ascribed to the action of light\*.

7thly, With respect to the emission of light by diamonds and other stones, it is easily accounted for upon other principles; and the arguments founded upon the electric spark not being sensibly diminished will meet with a satisfactory solution by considering the extreme rarity of light, and the minuteness of its particles.

It is, therefore, almost universally agreed by the moderns, that light consists of a number of extremely minute particles, which are actually projected from the luminous body, and act by their projectile force upon our optic nerve. Concerning the nature of these particles, or rather of the matter of which they consist, there is less unanimity in the philosophical world.

It is an opinion supported by the most respectable names, that light is a substance perfectly distinct from the matter of fire, and which excites ignition

\* “ It was conjectured by some, that the rays of the sun dispersed those parts of the bodies on which colours depended; but Bonzius observed, that when ribbons were exposed on white paper, the colours vanished from both their sides, but that nothing could be found near the places where they had lain.”  
*Priestley's Optics*, 381.

when concentrated by a burning glass, merely by its mechanical force upon the matter of heat. Others of equal eminence have contended, that light is no other than fire in a projectile state. Fire, according to these philosophers, is produced by the accumulation or concentration of the particles; light is the effect of the rapid projectile motion of the same particles. Fire or heat may therefore exist to a considerable degree, as it is found to do occasionally in metallic bars, without being sufficiently disengaged to assume the projectile state, and to be forcibly emitted or projected from the burning body. The same matter may also exist in its active and projectile state, or, in other words, in the form of light, but too much diffused to produce the sensation of burning, or to effect the dissolution of any body, or the separation of its parts by combustion. To the great elasticity of the matter of fire, so obvious in all the phenomena of fluidity, both these effects are ascribed. When a quantity of this matter is introduced into any solid body, the repulsion which exists between its particles will occasion the dissolution of that body; and when it becomes perfectly free and disengaged, the same repulsion will cause a quantity of its particles to be emitted with a rapid projectile force, and will produce the effects of light \*. The light of the sun is considered as "the same matter propelled by the same powers, in greater

\* When we consider that the elasticity of aeriform fluids, is owing to the matter of fire; that a cannon ball is propelled only

greater quantity and with greater vigour\*.” The atmosphere through which light has to pass in proceeding from the sun to us is in all probability of infinitely greater purity than ours, and consequently, according to the laws of motion, the projectile force of the rays of light is very little diminished in their passage from the great source of both light and fire.

The theory which is here advanced appears to rest chiefly on the great fact of the sun’s rays, when concentrated by a burning glass, producing all the phenomena and effects of elementary fire. There are, however, other facts which countenance the opinion. Sir Isaac Newton observes, that all bodies, when heated beyond a certain degree, emit light, and shine. Light also accompanies the electric fire, whenever it exists in a disengaged or projectile state.

only by the excess of the repellant powers of parts of this matter, above the forces with which they are attracted by the gross parts of gunpowder, or of the airs emitted during the deflagration of it; that the velocity of the ball is incomparably less than it would be if, it were shot through an unresisting medium; and that even this latter velocity would be an inadequate representation of that, with which the parts of the fiery matter are shot forth, in the first instant of their liberation from the combustible body which held them closely approximated; we find the natural powers already described, sufficient in themselves, for the projection of these parts, with all the velocity experienced in the light of flaming bodies on earth, and to every distance at which it has been perceived.’

*Higgins’s Experiments and Observations, p. 338.*

\* Higgins’s Experiments and Observations, p. 339.

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The absorption of light by the darker colours is also found to have an extraordinary effect in the production of heat; but the experiments to this effect have been already related\*.

That light (or more properly according to this theory, the matter of fire) does not always produce actual heat, is accounted for from the minuteness of the particles, and the extreme rarity which, from its repulsive principle, the fluid is enabled to assume. It was before stated that light must be exceedingly concentrated to produce ignition. A plane mirror reflects the light in too diffused a state; but a concave mirror collects and converges the particles to a point, and is therefore capable of producing ignition; and yet we have seen that the light of the moon will not, in the most condensed state, produce the least degree of heat, though the most delicate thermometers should be employed. The light which is emitted by putrescent substances, by the glow-worm, and some other insects, is analogous to the light of the moon in this respect; it is of too faint and rare a nature to produce heat or ignition. In the same manner, when the rays of light pass through a transparent medium, they succeed each other at an immense distance†. If, therefore, the rays concentrated by the most powerful burning glass are made to pass through a phial containing spirits of wine, or through any other transparent inflammable substance, the latter will not be set on fire; but if

\* See p. 76.

† That of 1,000 miles.

there

there is any opake body (as a spoon or other vessel) placed under the spirit or the transparent body, which by absorbing may serve to accumulate the particles of light, the spirit or inflammable matter will be immediately inflamed. Conformably to these principles it is found, that the atmosphere is not warmed by the mere passage of the sun's rays through it, but chiefly by the heat which is collected by the earth, and which is thence imparted to the air. Thus the air, at the summits of high mountains, is always cold, because they are too much elevated above the general surface of the earth to derive any considerable advantage from this circumstance.

When these facts are fairly considered, the system which supposes light to be a modification of the matter of fire, or a combination of that element with some unknown principle, must be allowed to be at least probable. It has however been customary to consider distinctly the properties of light, without a reference to its analogy with the matter of fire, and in this mode it will be necessary, on the present occasion, to proceed.

The first remarkable property of light is its amazing VELOCITY. In the short space of *one second* a particle of light traverses an extent of *one hundred and seventy thousand miles* \*, which is so much swifter than the progress of a cannon ball, that the light is enabled to pass a space in about eight minutes, which could not be passed with the

\* Nicholson's Phil. vol. i, p. 258.

ordinary velocity of a cannon ball in less than thirty-two years \*. The velocity of light is also found to be uniform, whether it is original, as from the stars, or reflected only, as from the planets.

The mode of calculating the velocity of light is a branch of astronomy rather than of natural history. It will suffice therefore in this place to remark, that by mathematical observations made upon the transits of Venus in 1761 and 1769, the diameter of the earth's orbit was found to be about 163,636,800 geographical miles. When, therefore, the earth happens to be on that side of her orbit which is opposite to Jupiter, an eclipse of his satellites, or any other appearance in that planet, is observed to take place fifteen or sixteen seconds later than it would have done if the earth had been on that side of her orbit which is nearest to Jupiter †. From the very accurate observations of Dr. Bradley, it appears that the light of the sun passes from that luminary to the earth in eight minutes and twelve seconds.

The next property of light, to which it is proper to advert, is, that it is detached from every luminous or visible body in all directions, and constantly moves in **RIGHT LINES**. It is evident that the particles of light move continually in right lines, since they will not pass through a bended

\* Nicholson's Phil. vol. i. p. 257.

† See Newton's Optics, l. ii. p. 3. prop. 11. Priestley's Optics, p. 140. Nicholson's Phil. vol. i. p. 136.

tube, and since if a beam of light is in part intercepted by any intervening body, the shadow of that body will be bounded by right lines passing from the luminous body, and meeting the lines which terminate the interceding body. This being granted, it is obvious, that the rays of light must be emitted from luminous bodies in every direction, since, whatever may be the distance at which a spectator is placed from any visible object, every point of the surface which is turned towards him is visible to him, which could not be upon any other principle.

The RARITY of light, and the minuteness of its particles, are not less remarkable than its velocity. If indeed the Creator had not formed its particles infinitely small, their excessive velocity would be destructive in the highest degree. It was demonstrated, that light moves about two million of times as fast as a cannon ball\*. The force with which moving bodies strike, is in proportion to their masses multiplied by their velocities; and consequently if the particles of light were equal in bulk to the two millioneth part of a grain of sand, we should be no more able to endure their impulse than that of sand shot point blank from the mouth

\* A cannon ball flies with a velocity of about a mile in eight seconds. Nicholson's Phil. vol. i. p. 257. During the late siege of Gibraltar, there were two boys, who used to be stationed on the works, and whose quick sight enabled them to give notice to the workmen of the approach of a ball from the enemy's works.—*Drinkwater's Gib.*

of a cannon \*. The minuteness of the rays of light is also demonstrable from the facility with which they penetrate glass, crystal, and other solid bodies, which have their pores in a rectilinear direction, and that without the smallest diminution of their velocity, as well as from the circumstance of their not being able to remove the smallest particle of microscopic dust or matter which they encounter in their progress. A further proof might be added, that if a candle is lighted, and there is no obstacle to obstruct its rays, it will fill the whole space within two miles around it almost instantaneously, and before it has lost the least sensible part of its substance †.

To the velocity with which the particles of light are known to move may, in a great measure, be attributed the extreme rarity and tenuity of that fluid. It is a well-known fact, that the effect of light upon the eye is not instantaneous, but continues for a considerable time ‡. Now we can scarcely conceive a more minute division of time than the one hundred and fiftieth part of a second. If, therefore, one lucid point of the sun's surface emits one hundred and fifty particles of light in one second, we may conclude that this will be sufficient to afford light to the eye without any seeming intermission; and yet, such is the velocity with which light proceeds, that still these particles will be at

\* Nicholson's Phil. vol. i. p. 257.

† Enfield's Phil. 131.

‡ Nicholson's Phil. vol. i. p. 258.



least *one thousand miles* distant from each other\*. If it was not indeed for this extreme tenuity of the fluid, it would be impossible that the particles should pass, as we know they do, in all directions without interfering with each other. In all probability the splendour of all visible objects may be in proportion to the greater or less number of particles, which are emitted or reflected from their surface in a given space of time; and if we even suppose three hundred particles emitted successively from the sun's surface in a single second, still these particles will follow each other at the immense distance of above five hundred miles.

That light is, however, not destitute of **FORCE** or **MOMENTUM**, has been proved by the experiment of Mr. Mitchel, already mentioned †. On that experiment the following calculation is grounded. If the instrument weighed ten grains, and the velocity with which it moved was one inch in a second, the quantity of matter contained in the rays which fell upon the instrument in that time was equal to the twelve hundred millioneth part of a grain; the velocity of light exceeding the velocity with which the instrument moved in that proportion. The light in this experiment was collected from a surface of about three square feet, which reflecting only half what falls upon it, the quantity of matter contained in the rays of the sun incident upon a square foot and half of surface is no more than one twelve hundred mil-

\* Priestley's Optics, p. 385.

† See p. 73.

lioneth

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lioneth part of a grain. But the density of the rays of light at the surface of the sun is greater than at the earth in the proportion of 45,000 to 1. There ought therefore to issue from one square foot of the sun's surface in one second  $\frac{1}{45000}$ th part of a grain of matter to supply the consumption of light; that is at the rate of a little more than two grains a day, or about 4,752,000 grains, or 670 pounds in 6,000 years, which would have shortened the sun's diameter about ten feet, if it was formed of matter of the density of water only\*.

Thus we see there are little grounds for any reasonable apprehensions concerning the body of the sun becoming exhausted by the consumption or waste of the matter of light, if the immensity of his diameter (878,808 English miles) is considered. It is, however, not impossible that there are means by which the sun may be enabled to receive back again a part of that light or fire which he is continually emitting; it is not impossible that this world, and the other planets, may have a power of reflecting back a certain portion of their light within the sphere of the sun's attraction, or that the fixed stars or suns may have some power of replenishing one another. After all, we have no right to suppose our world, or the system of which it makes a part, designed for an eternal duration; its existence is doubtless proportioned to the ends which were intended to be accomplished in it; but with respect to

\* Priestley's Optics, p. 389.

the period of its termination, there is no chain of moral or physical reasoning which appears to conduct to any satisfactory conclusion.

Notwithstanding the minuteness of the particles of light, and the amazing velocity with which they are projected, they are found, by a variety of experiments, to be subject to the same laws of **ATTRACTION** and repulsion that govern all other bodies. On this principle the majority of philosophers have explained the phenomena of the Bolognian stone, and what are called the solar phosphori.

The discovery of the Bolognian phosphorus, as related by Mr. Lemery, has already been detailed. The property of imbibing and emitting light is not, however, confined to one species, but is common to all the varieties of that mineral, which is called ponderous spar.

The light which they emit bears an analogy to that which they have imbibed. In general, the illuminated phosphorus is red; but when a weak light has been admitted to it, or when it has been received through pieces of white paper, the emitted light is of a pale white \*.

It has been already remarked †, that an artificial phosphorus may be obtained from all substances which can be reduced to a calx by burning only, or by solution in the nitrous acid. Some diamonds, however, as well as emeralds and other precious stones, are found to have the same property without

\* Prieſtley's Optics, p. 363, 364.

† See Chap. 1.

any chemical preparation; and a diamond has been known to retain its virtue of emitting light, after being buried in wax six hours \*. In fact, Beccaria has observed, that almost all natural bodies have the power of imbibing light, and of emitting it in the dark. To metals and water, however, he could not communicate the slightest degree of this property; but he found that although water in its fluid state could not be made to shine in the dark, ice and snow had this property in a remarkable degree †.

The light which is emitted from putrid substances and rotten wood, also that of *ignes fatui*, and other similar meteors, proceeds from a different cause, and will be explained in another part of this work, to which the subject more properly appertains.

To the principle of attraction Newton has also referred one of the most extraordinary phenomena of light; that on which the science of optics, strictly speaking, principally depends, and on which most of the optical instruments in use are constructed; I speak of what is called the REFRACTION of light, or that deviation or bending which its rays suffer in passing obliquely out of one medium into another, such as out of air into water, glass, &c.; but this refraction can be observed in passing through transparent mediums only. These mediums, whether

\* Priestley's Optics, p. 367.

† Priestley's Optics, p. 368, 369, 370. The nature of these phosphori will be explained more at large under their proper head, in Book VI. Chap. 35.

solid or fluid, must be considered as masses whose pores, placed in right lines in all directions, are either full of the matter of light, according to the opinions of Descartes and Huyghens, or they are so constructed as to permit the light to pass in right lines, according to Newton.

There are two circumstances to be considered in the passage of the rays of light out of one medium into another: First, the nature of the medium; secondly, the obliquity of the rays to the plane which separates the two mediums.

1. The denser the refracting medium, or that into which the ray passes, is, the greater will be its refracting power; and of two refracting mediums of the same density, that which is of a fat or inflammable nature will have a greater refracting power than the other.

2. The angle of refraction depends on the obliquity of the rays falling on the refracting surface being such always that the sine of the incident angle is to the sine of the refracted angle in a given proportion.

The incident angle is the angle made by a ray of light, and a line drawn perpendicular to the refracting surface at the point where the light enters the surface; and the refracted angle is the angle made by the ray in the refracting medium with the same perpendicular produced. The sine of the angle is a line which serves to measure the angle, being drawn from a point in one leg perpendicular to the other.

In passing from a rare into a dense medium, or from one dense medium into a denser medium, a ray of light is refracted towards the perpendicular; on the contrary, in passing from a dense medium into a rare medium, or from one rare medium into a rarer, a ray of light is refracted from the perpendicular.

If the eye, therefore, is placed in a rarer medium, an object seen in a denser medium, by a ray refracted in a plane surface, will appear larger than it really is, as things seem larger under water, to an eye in the air, than they do out of it, and the contrary\*.

To these laws of refraction is to be attributed the difference between the real and the apparent rising of the sun, moon, and stars, above the horizon. The horizontal refraction is a little more than half a degree, whence the sun and moon appear above the horizon when they are entirely below it. From the horizon the refraction continually decreases to the zenith. Refraction is increased by the density of the air, and consequently it is greater in cold countries than in hot; and it is also affected by the degree of cold or heat in the same country.

On the principle of the refraction of light all dioptrical † instruments are constructed. As the greater the obliquity with which a ray strikes a

\* "As things seem large which we through mists descry,  
"Dulness is ever apt to magnify." POPE.

† *Δια*, (*dia*, "through") Gr. and *ὀφθαλμοι*, (*optomai*) "to see."

dense transparent body the greater the refraction, it is evident that when a collection of rays pass in a strait line, and enter a body of any form approaching to that of a globe or sphere, only one, viz. that which enters at its center, will enter in a direct line; all the rest will strike it more or less obliquely, and will all consequently undergo a proportionable degree of refraction. As in a dense body of such a form the rays will be all refracted, converged, or bent inwards towards the central ray, there will be a point where they must all meet, and this point is called the focus. In this point they will therefore cross each other, and diverge again in the same proportion, as it is the property of light constantly to proceed in a strait line, whatever direction it takes. In passing through a glass or lens, which is equally convex on both sides, the focus or point where the rays meet will be equal to the semidiameter of the glass's convexity, that is, half the diameter of that circle of which the convexity of the lens is an arch. As the rays cross each other after they pass the focus, it is evident that any image seen through a lens, beyond the focal distance, will be inverted, as may be proved by an easy experiment, viz. by holding a lens or magnifying glass between a candle and a sheet of paper suspended on the wall, at a proper distance, when the image of the candle will appear on the paper inverted; and the reason of this is extremely clear, for it is evident that the upper rays, after refraction, are those which proceeded from the under part of the luminous body, and the under rays

are those which come from its top. The rays are therefore only inverted, and the image remains unimpaired.

Upon the same principles, if parallel rays pass directly through a glass which is concave, they will diverge, or be bent outwards by the refractive power, exactly in proportion to the concavity, that is, in proportion to the obliquity with which they strike on the glass; and the point of divergence, or negative or virtual focus, will be in the same proportion to the concavity of the glass as in the preceding instance. Converging rays, passing through a concave glass, will also be proportionally bent out of their course, and will not come to a point or focus so soon as they would otherwise have done.

In the middle part of the human eye, behind the pupil, there is placed a perfect convex lens, of a clear, transparent, jelly-like matter, which is called the crystalline humour; by this the rays of light are made to converge to a point, and cross each other so as to form a small inverted image of the object on the optic nerve, which is expanded on the back part of the eye, and called the retina. The apparent magnitude of objects will consequently depend upon the size of the inverted image, or, in other words, upon the angle which the rays of light form by entering the eye from the extremities of any object; hence convex lenses magnify, because the rays proceeding from any object, and passing through the lens, being made to converge sooner than they otherwise would, the angle is greater, and the object apparently



rently larger, or nearer, than when viewed by the naked eye; hence too a concave lens makes an object appear smaller, or more distant, because by its causing the rays of light to diverge, the visual angle is proportionably diminished.

Light is not only subject to the law of attraction, but to that of repulsion also; in other words, it is repelled, or REFLECTED, from all bodies which are not transparent. In reflection, light is still observed to proceed in strait lines, and the angle of reflection is equal to the angle of incidence; that is, when a ray of light strikes obliquely upon a mirror, it will be regularly returned with the same degree of obliquity with which it came; hence, when light is reflected from spherical bodies, the rays will converge or diverge as when it passes through bodies of a similar form, only that the effect will be reversed; hence rays reflected from a concave mirror, or speculum, will converge to a focus, the distance of which is in proportion to the concavity of the mirror.

By concentrating the rays of light, or, more properly speaking, by causing them to converge to a focus, heat is produced; hence every convex lens, and every concave mirror, is a burning glass, and the focal point is that in which the heat is most powerful.

Light is, however, not so simple a substance as it may be supposed upon superficially considering its general effects; it is indeed found to consist of particles which are differently refrangible, that is, some

of them may be refracted more than others in passing through certain mediums, whence they are supposed by philosophers to be different in size. The common optical instrument, called a prism, is a triangular piece of glass, through which, if a pencil or collection of rays is made to pass, it is found that the rays do not proceed parallel to each other on their emergence, but produce on an opposite wall, or any plain surface that receives them, an oblong spectrum, which is variously coloured, and it consequently follows, that some of the rays or particles are more refrangible than others.

The spectrum thus formed is, perhaps, the most beautiful object which any of the experiments of philosophy present to our view. The lower part, which consists of the least refrangible rays, is of a lively red, which, higher up, by insensible gradations, becomes an orange; the orange, in the same manner, is succeeded by a yellow; the yellow, by a green; the green, by a blue; after which follows a deep blue or indigo; and lastly, a faint violet.

In the succeeding chapters I shall treat of the reflection and refraction of light in a more particular and scientific manner; but as the subject is somewhat abstruse, these preliminary observations appeared necessary, in order to render it more easy and intelligible to the general reader.

## C H A P. III.

## OF THE REFLECTION OF LIGHT.

*Angle of Reflection equal to the Angle of Incidence.—Reflection from plane Surfaces.—From spherical Surfaces.—Explanation of the Phenomena of concave Mirrors.—Of the projecting Figure which appears from them before the Glass.—Use of convex Mirrors to Travellers.*

**I**T has been already proved, that the rays of light proceeding from any luminous body always move in *strait* lines, unless this direction or motion is changed or destroyed by certain circumstances\*, which are now more particularly to be considered. The direction is changed by reflection, refraction, and inflection; the motion is destroyed by absorption. It will be most consistent with a lucid order, first to examine the nature of reflection.

A common experiment of children with a piece of glass opposed to the sun, and casting the light into various places at will, shews that the rays of light may be reflected by certain bodies, and by more accurate experiments it is found, that when a

\* This is the principle on which all the reasoning with respect to optics depends, and it is upon this principle that all the lines and figures referred to in the following pages are drawn.

ray of light is reflected by any surface, the angle of incidence is equal to the angle of reflection. By the angle of incidence is meant, the angle made by the ray of light with a perpendicular to the reflecting surface at the point on which the ray falls; and by the angle of reflection, the angle which the ray makes with the same perpendicular on the other side. Thus, let  $Q$ , Plate I. Fig. 1. be a point from which rays diverging fall on the reflecting surface  $AB$ , and let  $QD$ ,  $QE$  be two incident rays. At  $D$ ,  $E$  draw the perpendiculars  $DC$ ,  $EF$  to  $AB$ , and make the angles  $CDG$ ,  $HEF$  equal to  $QDC$ ,  $QEF$ , and the rays  $QD$ ,  $QE$  will be reflected by the surface in the directions  $DG$ ,  $EH$ .

Since no surface has hitherto been found so perfectly smooth, that it has not some inequalities in it to be discovered by a microscope, and yet these inequalities do not affect the law thus discovered for reflected rays, it is generally concluded, that the power which produces this change in the direction of the rays, acts at some small distance from the surface. The point  $Q$ , from which the rays diverge, is called the focus of diverging rays; and as, after reflection, the rays appear to have diverged from a point behind the surface, that point is called the focus of reflected rays. To find this point, produce the lines  $GD$ ,  $HE$  till they meet the perpendicular drawn from  $Q$  on the reflecting surface produced, if necessary. Let  $QMq$  be this perpendicular, which  $GD$  meets in  $q$ ; then, since  $QDC$  is  
equal

equal to  $GDC$ ,  $QDM$  is equal to  $GDB$  but  $GDB$  is equal to  $MDq$ ; in the two triangles  $QDM$ ,  $MDq$ , there are two angles in the one equal to two angles in the other, and one side  $MD$  common to both, therefore  $QM$  will be equal to  $Mq$ . The same may be proved also of the intersection of the lines  $HEq$  and  $QMq$ . Therefore the focus of rays reflected by a plane surface is at the same distance behind the surface, as the focus of diverging rays is before it \*.

If, instead of rays diverging from one point they diverge from several, the corresponding foci will be found in the same manner. Let  $QR$ , Fig. 2, be a surface, from every point of which draw perpendiculars to the reflecting surface as before, and  $qr$  will be the image of  $QR$ , or all the rays diverging from  $QR$  will, after reflection, appear to have diverged from  $qr$ .

Every object placed before a reflecting surface has its corresponding image. If the object is a plane surface, the image will also be a similar plane surface; if the object is a curvilinear surface, the image will correspond to it; and in all cases it is found in this manner, by perpendiculars drawn from the object to the reflecting surface, or the reflecting surface produced.

\* To the general reader, who has no previous acquaintance with philosophy, a part of this chapter will appear intricate and difficult. Let it be remembered, however, that it embraces some of the most difficult problems in natural science, which, however, could not be omitted, and they are rendered as plain as the nature of the subject would admit.

To

To see any object, the eye must be so placed that some of the rays of light diverging from the object may fall upon the eye; and if, by looking upon a reflecting surface we see an image, we should, if our judgment had not been corrected by experience, conceive an object to be placed behind the surface from which these rays diverged. Now, as an object may be placed in such a situation before the reflecting surface that no rays can be reflected to our eyes, we shall not always see an object by reflection, and the places of the object, the spectator, and the reflecting surface, must be taken into consideration. Let  $QR$  be an object before the reflecting surface  $AB$ ,  $qr$  its image, as before, Fig. 2, and  $O$  the place of the spectator. Join  $OA$ ,  $OB$ , and produce the lines  $OA$ ,  $OB$  indefinitely to  $T$  and  $P$ , unless the image lies within the lines  $AT$ ,  $BP$  the object will not be seen by reflection. Let  $fg$  without this space be the image of  $FG$ , and join  $Of$   $Og$ , and since these two lines do not any where cut the reflecting surface, it is evident that by looking on the surface we shall not see the object. We shall see part of  $QR$ , because part of  $qr$  lies within the space abovementioned, and to find the part of  $QR$  which is visible by reflection from the point  $s$ , where  $OP$  cuts  $qr$ , draw  $sS$  perpendicular to  $AB$  produced. Then the ray  $SB$  will be reflected in the direction  $BO$ . Now join  $Oq$  cutting  $AB$  in  $D$ , and join  $QD$ . The ray  $QD$  will be reflected in the direction  $DO$ , and the part of the object visible by reflection will be seen in part of the reflecting surface only

only D B. All the rest being superfluous as to this object. Thus we can always find by what rays, and by what part of a reflecting surface, an object is seen. The limits of the space in which an object must be placed to appear visible by reflection are, on these principles, easily determined. Join O B, O A, and make the angles I B K, L A E equal to O B I, O A L; then every object placed within the lines B K, A E indefinitely produced, will be visible at O by reflection.

Thus, when we are placed before a looking-glass in a room, part of the room only is visible; as we walk backwards and forwards other parts appear and disappear in succession, and some parts of the room are never seen in the glass.

When a person stands before a looking-glass of the same dimensions with himself, his image appears to occupy the half of it, or, in other words, a looking-glass of half his dimensions is capable of shewing him the whole of his figure. Let A B, Fig. 3. be an object placed before the reflecting surface  $g b i$  of the plane mirror C D; and let the eye be at  $o$ . Let A  $b$  be a ray of light flowing from the top A of the object, and falling upon the mirror at  $b$ : and  $b m$  be a perpendicular to the surface of the mirror at  $b$ , the ray A  $b$  will be reflected from the mirror to the eye at  $o$ , making an angle  $m b o$  equal to the angle A  $b m$ : then will the top of the image E appear to the eye in the direction of the reflected ray  $o b$  produced to E, where the right line A  $p$  E, from the top of the object, cuts the right line  $o b$  E, at E. Let B  $i$  be

be a ray of light proceeding from the foot of the object at  $B$  to the mirror at  $i$ , and  $ni$  a perpendicular to the mirror from the point  $i$ , where the ray  $Bi$  falls upon it: this ray will be reflected in the line  $io$ , making an angle  $nio$ , equal to the angle  $Bin$ , with that perpendicular, and entering the eye at  $o$ : then will the foot  $F$  of the image appear in the direction of the reflected ray  $oi$ , produced to  $F$ , where the right line  $BF$  cuts the reflected ray produced to  $F$ . All the other rays that flow from the intermediate points of the object  $AB$ , and fall upon the mirror between  $b$  and  $i$ , will be reflected to the eye at  $o$ ; and all the intermediate points of the image  $EF$  will appear to the eye in the direction-line of these reflected rays produced. But all the rays that flow from the object, and fall upon the mirror above  $b$ , will be reflected back above the eye at  $o$ ; and all the rays that flow from the object, and fall upon the mirror below  $i$ , will be reflected back below the eye at  $o$ : so that none of the rays that fall above  $b$ , or below  $i$ , can be reflected to the eye at  $o$ ; and the distance between  $b$  and  $i$  is equal to half the length of the object  $AB$ , if the eye, or  $o$ , is in the line  $AB$  produced, for then  $Ab$  will be equal to  $bo$ , and  $Ab$  is equal to  $bE$ . Therefore  $bE$  is equal to  $ob$ , and  $ob$  is one half of  $oE$ , and consequently  $ib$  (from similar triangles) is equal to one half of  $EF$  or  $AB$ .

In rooms where looking-glasses are placed parallel and opposite to each other, a person looking into one sees several images of himself; for rays



Fig. 1.

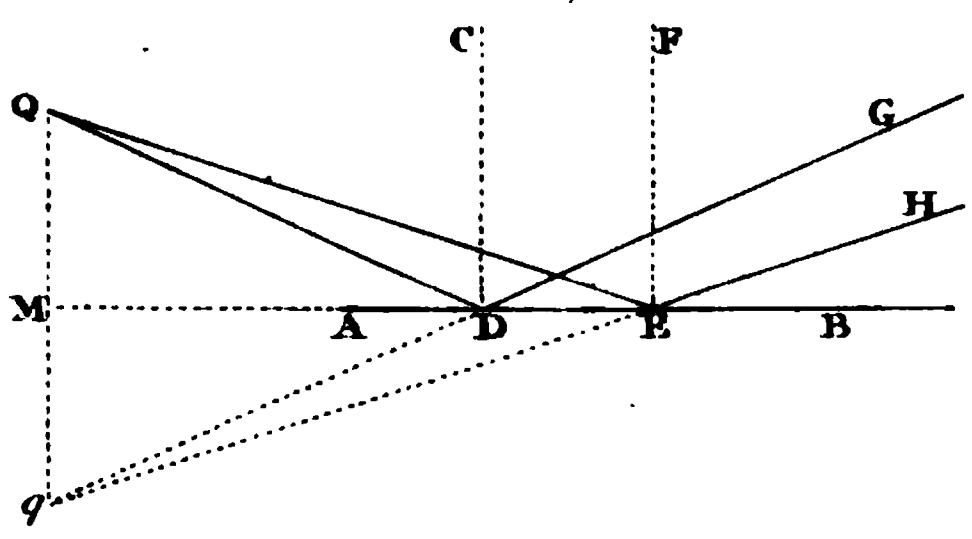


Fig. 2.

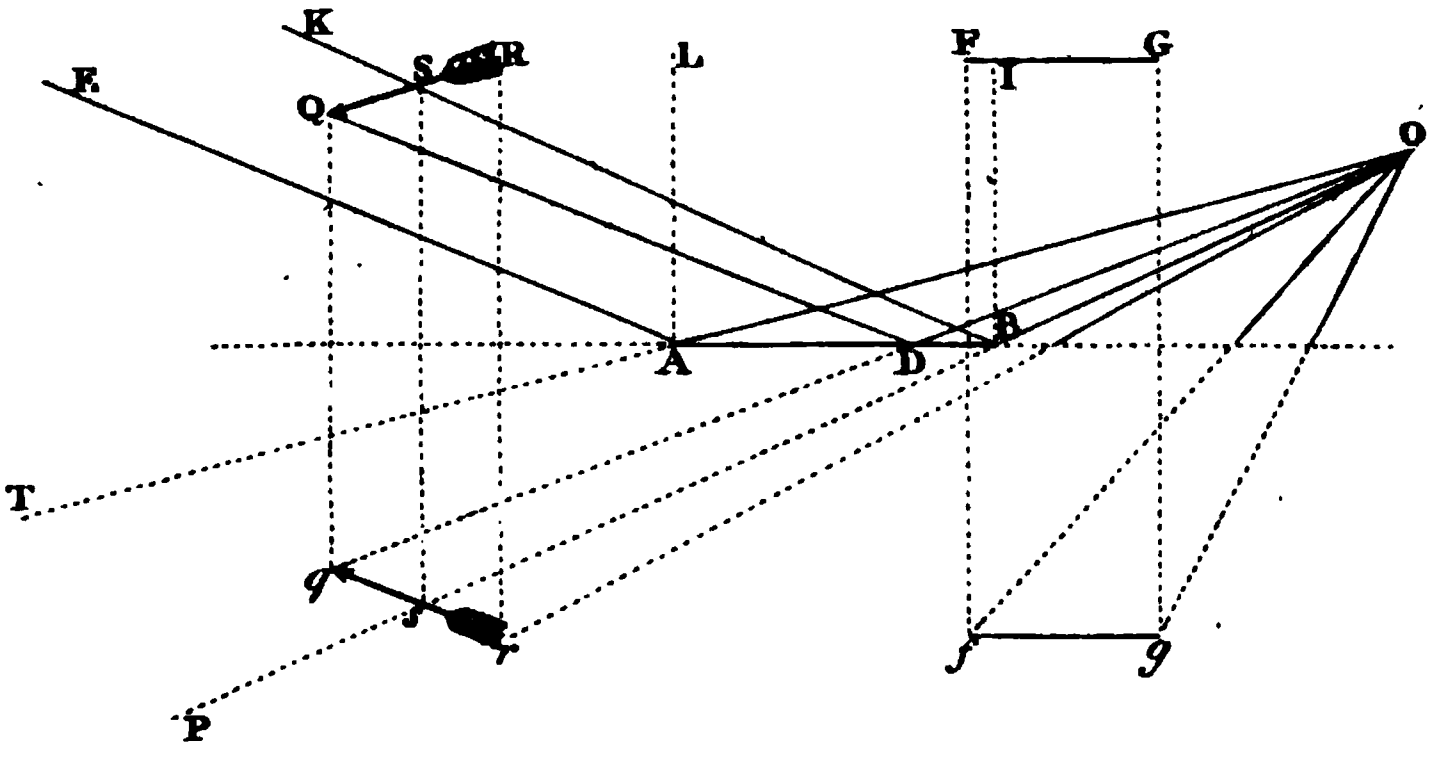
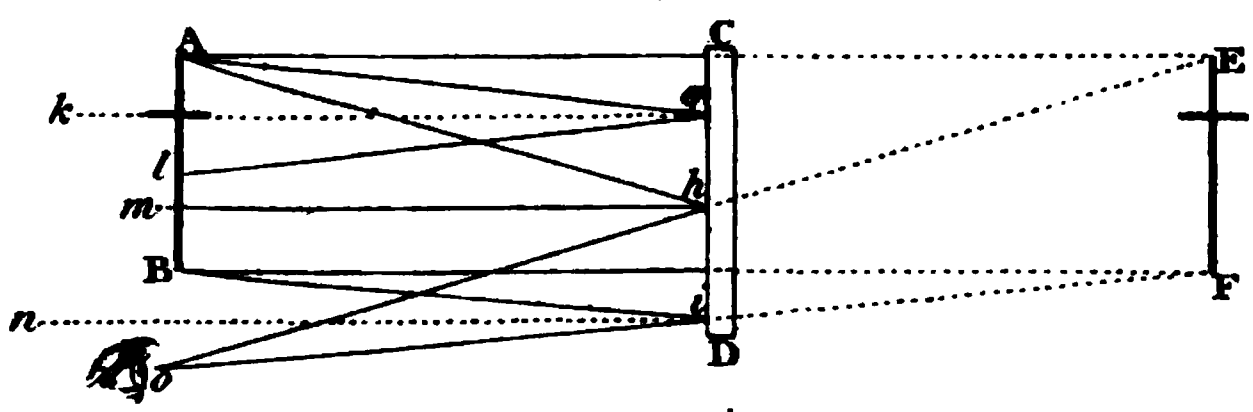


Fig 3





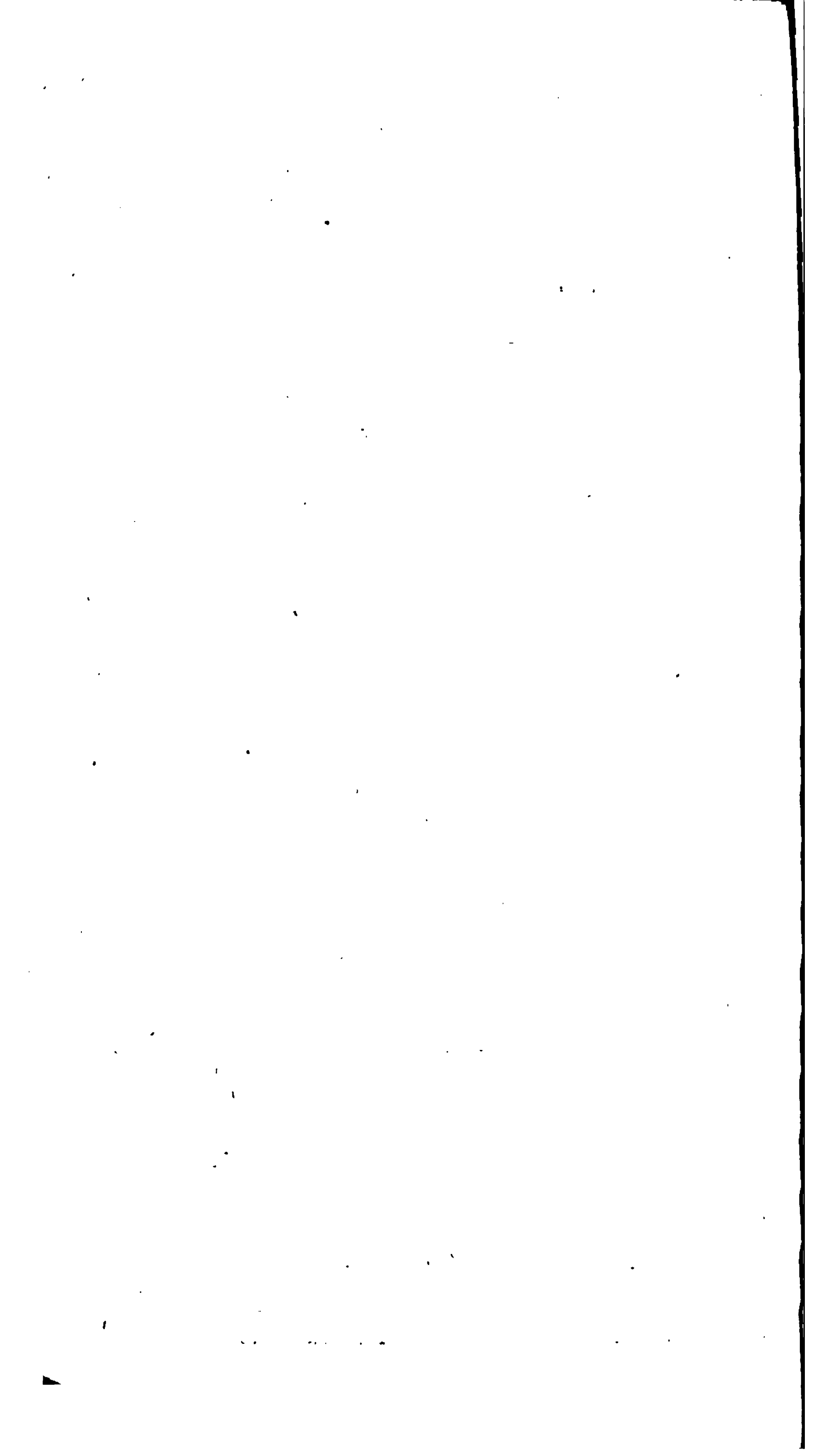
will be reflected from one glass to the other, and each image becomes an object to the other glass. If, instead of being parallel, the glasses were placed opposite to each other, but making an acute angle, there will be several images of the same object appearing to be placed in a circle, whose centre is the vertex of the acute angle, and radius the distance of the object from that vertex. Let  $MNOP$  Plate II. (Fig. 4.) two surfaces produced, meet in  $b$ , and let  $Q$  be an object, and  $q, c$  its images in the respective glasses. Join  $bq, bQ$ , and the triangles  $Qab, qab$ , having two sides and an angle respectively equal, the third side  $Qb$  is equal to  $qb$ . So  $bc$  is equal to  $bQ$ ; and in the same manner the images of  $q$ , and  $c$  found in the opposite glasses, will be equidistant from  $b$ .

The places of images, made by the reflection of the rays of light from plane surfaces, are easily determined: but when rays are reflected by curvilinear surfaces, the difficulty of determining the place of the image is considerably increased. I shall endeavour to shew the manner of investigating this subject in the simplest cases.

Let  $AB$  (Fig. 5.) be a spherical surface, of which  $C$  is the centre, reflecting the rays of light both on the concave and convex side; and let  $QE$ , a ray of light parallel to the radius  $CD$ , be incident on the surface at  $E$ . After reflection on the concave side, the ray will proceed in the direction  $Eq$ , making the angle  $qEC$  equal to  $QEC$ ; but the ray  $QE$  reflected by the convex surface

surface will proceed in the direction  $E K$ , making the angle  $K E I$  equal to the angle  $Q E I$ . The greater the distance of  $E$ , the point of incidence, is from  $D$ , the vertex of the surface, the farther will the intersection of the reflected ray of radius  $C D$  be from the center of the surface. Since  $Q E$  is parallel to  $C D$ , the angle  $Q E C$  is equal to the angle  $E C q$ ; therefore the angles  $q E C$ ,  $q C E$  are equal to each other, and consequently  $q C$  is equal to  $q E$ . If  $E$  is very near to  $D$ ,  $q D$  and  $q E$  will be very nearly equal to each other, and the point  $q$  will then be very near to  $T$ , the point bisecting the radius of the surface. The parallel rays then falling upon the concave surface very near to  $D$  will converge, after reflection, very nearly to the point  $T$ , and that point may be considered, and is considered, as the focus after reflection of those rays; the aberration of every other ray, or the distance  $q T$  shall be afterwards considered. The parallel rays falling on the convex side will also, after reflection, appear to have diverged from this point,  $T$ , without any very material error. We may lay it down, therefore, as a principle, that rays falling upon a reflecting surface will, by the concave side, be made to converge to a point bisecting a radius drawn parallel to them, and by the convex side will be reflected so as to appear to diverge from a point bisecting the radius drawn parallel to them. This point,  $T$ , is called the focus; because, if the reflector is of sufficient magnitude, an inflammable object placed in that point may be set on fire by the





the reflected rays of the sun from the concave surface; and it is supposed that a degree of heat may be excited by a concave reflector and the sun's rays, greater than by any known application of artificial fire.

Let now (Fig. 6.) the rays diverging from a certain point be intercepted by a spherical reflecting surface, and let  $Q$  be that point, and  $AB$  the surface of which  $C$  is the center; and let  $qE$  be the reflected ray. Draw  $Cm$  parallel to  $qE$ , and  $Cn$  parallel to  $QE$ . By the principle above mentioned a ray diverging from the point  $m$  will, after reflection, cut the parallel radius  $Cn$  in  $n$ , bisecting the radius in that point; and, if a ray diverged from  $n$ , it will, after reflection, cut the parallel radius  $Cm$  in  $m$ , bisecting that radius; therefore  $Cm$ ,  $Cn$ ,  $CT$  are equal. Since the triangles  $QmC$ ,  $Cnq$  are similar,  $Qm : mC$ , or  $CT : : Cn$ , or  $CT : nq$ . The nearer  $E$  is to  $D$ , the nearer will the points  $m$  and  $n$  be to  $T$ ;  $Qm$  will be nearly equal to  $QT$ , and  $qn$  to  $qT$ . Therefore the focus of rays, after reflection, will be found, without very material error, by saying, as  $QT : CT : : CT : Tq$ . Calling therefore  $T$  the principal focus, its distance from the centre of the surface will be a mean proportional between its distances from the foci of diverging and reflected rays.

In Plate III. Fig. 7. the proposition is in the same manner demonstrated, by saying, that rays appearing to diverge from  $m$ , were reflected by the surface intercepting rays converging to  $n$ , and vice versa.

The foci of diverging and reflected rays are always on the same side of the principal focus. The greater the distance of  $Q$  from  $T$ , the less is the distance of  $q$  from  $T$ ; as  $Q$  approaches to  $T$ ,  $q$  removes from it; they meet together when rays are reflected by a concave surface in the center. When the focus of diverging rays is between the center and the principal focus, the focus of reflected rays is on the other side of the center. When  $Q$  is in  $T$ , the reflected rays are parallel; when  $Q$  is between  $T$  and the surface, the rays appear to diverge from a point on the other side of the surface. When rays are reflected by the convex surface, the focus of the reflected rays is always between the principal focus and the surface.

Having found the focus of reflected rays for a single point, we can, as before, find the situation of the image of any object, by considering the object as made up of innumerable foci of diverging rays. Let  $QR$  (Fig. 8.) represent an object before a spherical reflector, then join  $QC D$ , and in the line  $QD$  find the point  $q$ , the focus of rays after reflection, by the proportion laid down in the preceding instance. In the same manner find the point  $r$ , and, if necessary, find the corresponding foci to other points in the object  $QR$ , then  $qr$  is its image. This image will be either erect or inverted, according to the nature of the reflector, and the position of the object. First, if the reflector is a spherical concave, as in Fig. 8, and the distance of the object from the surface is greater than half the radius of



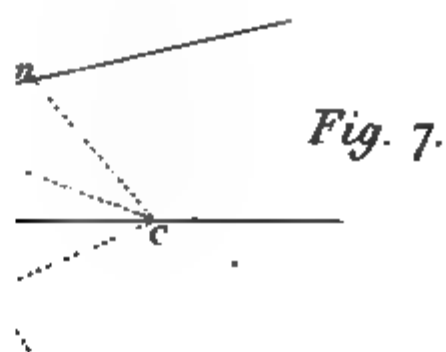
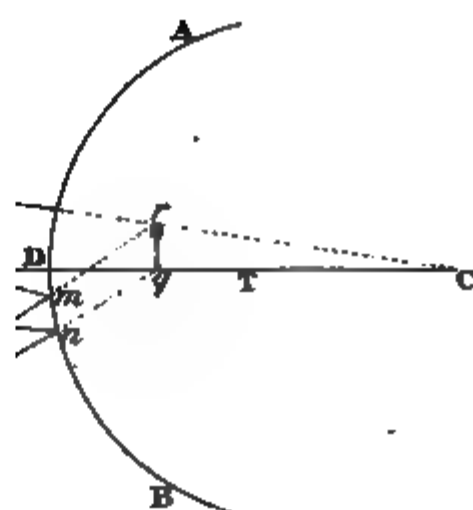
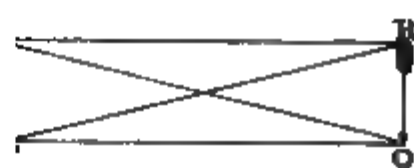
the reflector, the image will be inverted, and on the same side of the reflector with the object. If the distance of the object from the reflector is less than half the radius, the image will be erect, but on the other side of the reflector. This is seen in Fig. 9, where  $qr$  represents an object in the situation above-mentioned, and  $QR$  is its image. 2dly, The image of an object before a convex spherical reflector is always erect, as may be seen in Fig. 9.

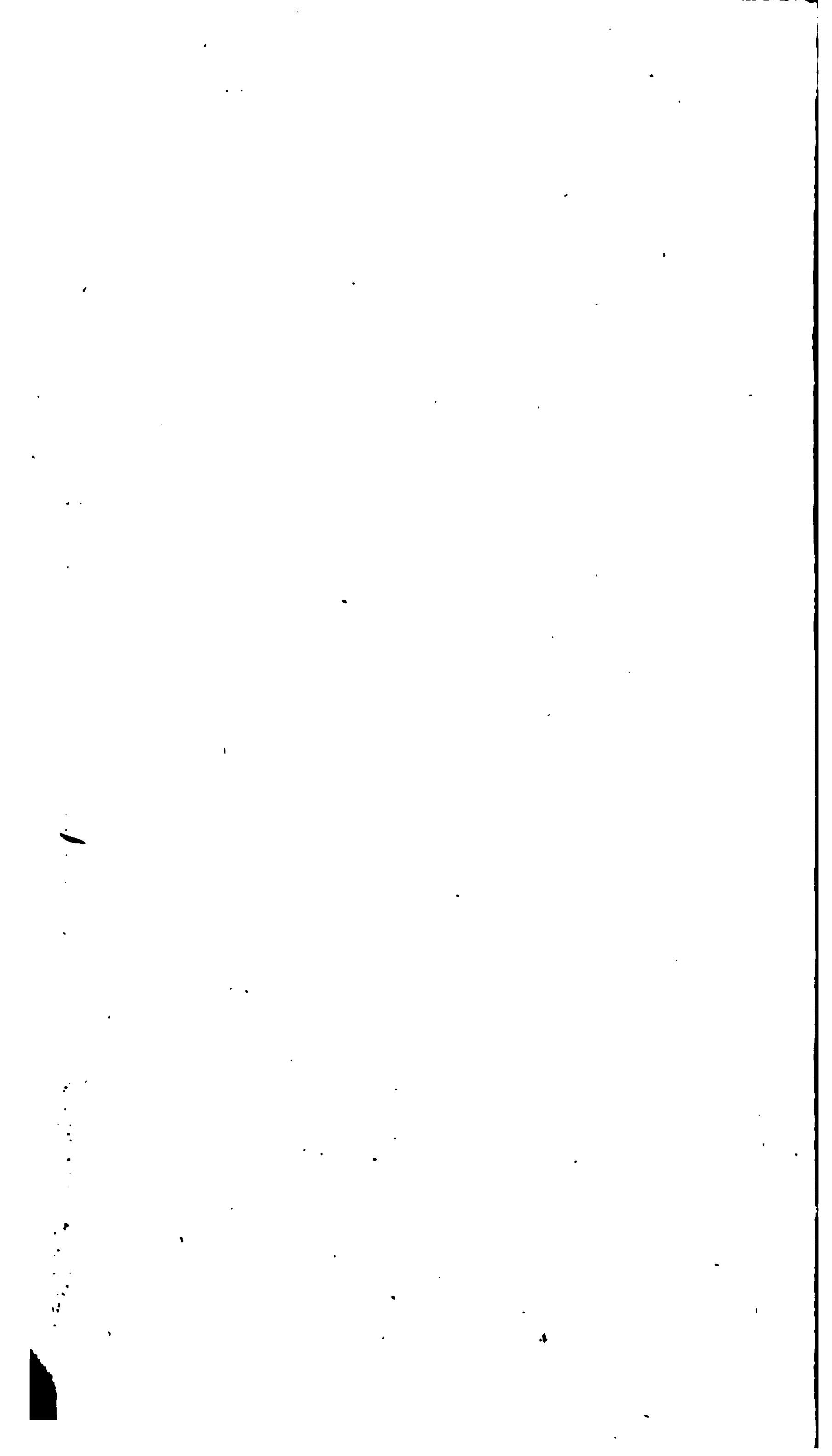
In plane reflectors images correspond, and are similar to their objects. It is not so in spherical reflectors, by which an image is made sometimes greater, sometimes smaller than the object. The concave reflector has the power of diminishing and magnifying. When the distance of the object from the reflector is greater than the radius, the image is always less than the object, for  $qr : QR :: Cq : CQ$ ; and in that case  $Cq$  being less than  $CQ$ ,  $qr$  must be less than  $QR$ . When the object is between the center and the principal focus, the image is greater than the object, for now  $qr$  being the object,  $QR$  is its image, and  $Cq$  being less than  $CQ$ , the object must be less than its image. When the object is between the principal focus and the reflector, the image is greater than the object; for supposing  $qr$  (Fig. 9.) to be the object, and  $QR$  the image,  $qr : QR :: Tq : TQ$ ; but  $Tq$  being less than  $TQ$ ,  $qr$  must be less than  $QR$ . When an object is placed before a convex spherical reflector, the image is less than its object; for (Fig. 9.)  $TQ$  being greater than  $Tq$ ,  $QR$  must be greater than  $qr$ .

To find whether an object may be seen in a reflector by a spectator in any situation, we draw lines from the eye to the image, and, if these lines are cut by the reflecting surface, the image is visible, and the part of the reflecting surface intercepted between these lines is that part which reflects the rays to the eye. Let  $O$  be the eye of the spectator, Fig. 8; join  $Oq$ ,  $Or$ , and produce them, if necessary, till they cut the reflecting surface in  $m$  and  $n$ , then  $mn$  is the part of the reflecting surface in which the image is seen; and the rays  $Qm$ ,  $Rn$ , reflected in the direction  $mO$ ,  $nO$ , are those by which the extreme parts of the object are seen.

This would be strictly true in all cases, if rays proceeding from an object made it always visible and clear; but we are accustomed from our infancy to determine on the nature and position of objects by rays diverging from them. To see, therefore, by reflected rays, they must appear to the eye to diverge from the image, which will not be the case when the eye is at a less distance from a concave reflector than the image. In that case our vision is confused, the image is behind us, and we can form no conception of it. But this will be farther explained when I come to treat on the nature of vision.

Upon the principles now laid down, we see the reason of those beautiful and deformed images made by objects placed before spherical reflectors, as also the changes produced in them by their various positions with respect to the reflector. When  
a person

*Fig. 8.*



a person is at a greater distance from a concave spherical reflector than the radius, he perceives an image, for instance, of himself, much diminished, standing upon its head before the reflecting surface in the air; as he walks towards the center, the image walks towards him, increasing in magnitude; as he walks from the center to the principal focus, his image appears confused, and he cannot ascertain any of its parts; as he walks from the principal focus to the surface, the image is again clearly visible, erect, greater than himself, but walking towards him, and diminishing constantly, till both object and image meet together in the reflecting surface.

From this property of the concave reflector to form the image of an object, in certain cases, before the reflector, many deceptions have been produced, to the great surprize of the ignorant spectator. He is made to see a bottle half full of water inverted in the air without losing a drop of its contents; as he advances into a room, he is tempted to exclaim with Macbeth, "Is this a dagger that I see before me!" and when he attempts to grasp it, it vanishes into the air.

A variety of similar appearances may be represented, which are all produced by means of a concave reflector, having an object before it strongly illuminated, care being taken that only the rays of light reflected from the object shall fall upon the concave reflector, placed in such a manner that the image shall be in the middle of the adjoining room; or, if in the same room with the object and reflector,

a screen must be placed so as to prevent the spectator from discovering them. A hole is then made in the partition between the two rooms, or in the screen, through which the rays pass, by which the image is formed. The spectator then, when he casts his eyes upon the partition or the screen, will, in certain situations, receive the rays coming through this small aperture. He will see the image formed in the air; he will have no idea, if not previously acquainted with optics, of the nature of the deception; and may either be amused, according to the inclination of his friends, with tempting fruit, or be terrified at the sight of a ghastly apparition.

The phenomena of convex speculums are different, and in most respects opposite, to those of the concave speculum. When a person looks in a convex spherical reflector, he sees an image of himself, erect, but diminished. As he walks towards the reflector, the image appears to walk towards him, constantly increasing in magnitude, till they touch each other in the reflecting surface.

From this property of diminishing objects, spherical reflectors are in great request with all lovers of picturesque scenery. Small convex reflectors are made in the shops for the use of travellers, who, when fatigued by stretching the eye to alps towering on alps, can by their mirror bring these sublime objects into a narrow compass, and gratify the sight by pictures which the art of man in vain attempts to imitate,

## C H A P. IV.

## O F R E F R A C T I O N.

*Refraction, what.—Law of Refraction.—Ratio of Refraction with respect to different Substances.—How the Situation of Objects is determined upon, seen through different Mediums.—How far the Situation of Objects is apparently altered by the Refraction of common Window Glass.—Refraction by spherical Surfaces.*

**B**Y experience we discovered that rays of light are reflected by many substances, and that the angle of reflection is equal to the angle of incidence: by experience, also, it has been discovered, that the direction of the rays of light is changed by their passage from one medium into another, and that this change of direction follows a determinate law. The space in which a ray of light moves, whether empty space, or space occupied by a peculiar substance, is called a medium; and in passing from pure space into any other medium whatever, or from any medium into a denser medium, a ray of light is bent towards the perpendicular on the surface separating the two mediums; in passing from a dense into a rarer medium, or from any medium into pure space, a ray of light is bent from this perpendicular; but a ray of light will only, in certain directions, pass out of a dense into a rarer medium; for when the angle

is of a certain magnitude, determined by the nature of the mediums, the ray, instead of being refracted, will be reflected back into its original medium.

The law of refraction is, that the sine of incidence is to the sine of refraction in a given ratio, and this ratio is discovered by experience. Thus, when a ray passes out of air into water, the ratio is as 4 to 3.

out of water into air, as 3 to 4.

air into glass, as 3 to 2.

glass into air, as 2 to 3.

air into diamond, as 5 to 2.

diamond into air, as 2 to 5.

Let  $HF$  be a ray of light incident on the surface  $AB$ , (Plate IV. Fig. 10.) of a dense medium  $ABCD$ , suppose it to be glass surrounded by air. Draw  $EFM$  perpendicular to  $AB$ , and make  $GFM$  such an angle, that the sine of  $HFE$  shall be to the sine of  $MFG :: 3 : 2$ , and the ray  $HF$  will in the glass move in the direction  $GF$ . When the ray comes to  $G$  it suffers another change in its direction by moving into air, and to find this direction, draw  $IGN$  perpendicular to  $CD$ , and make  $LGN$  such an angle, that the sine of  $FGI$  shall be to the sine of  $NGL :: 2 : 3$ , then the ray will move in the direction  $GL$ . Thus the whole progress of the ray is found to be in the direction  $HFG L$ , and by the same rule its progress through any number of mediums might be found.

The



The direction  $GL$  is parallel to the direction  $HF$ ; for the angles  $MFG$ ,  $FGI$ ,  $NGK$ , are equal; and since the sine of  $MFG$  : sine of  $MFI$  :: sine of  $NGK$  : sine of  $ngl$ , the angles  $ngl$ ,  $MFI$ , are equal, and consequently the angles  $ngl$ ,  $nio$ , are equal. Therefore the lines  $HO$ ,  $GL$ , are parallel.

Let  $FG$  (Fig. 10.) be a ray in a dense medium incident on  $G$ , and its direction after emergence be  $GL$ . The greater the angle  $FGI$  is, the greater will be the angle  $ngl$ . Suppose  $ngl$  to be a right angle, then the sine of  $FGI$  : radius :: sine of incidence : sine of refraction, and according to the law of refraction for the given medium, the limiting angle of incidence will be found for a ray to emerge. When the angle of incidence is greater than this angle thus found, the incident ray will be reflected back, as  $abc$ .

Let rays diverging from a point  $Q$  (Fig. 11, 12.) after refraction, move in the medium  $ABCD$ . To a person in this medium they will not appear to have diverged from  $Q$ , but from a point nearer to or farther off from him, according as the medium, in which he is, is denser, or rarer than the medium in which the point of diverging rays is situated. Let  $QI$  be an incident ray proceeding after refraction in the direction  $IM$ , cutting  $QO$  a perpendicular to the surface  $AB$  in  $q$ ,  $q$  will be the point from which the rays appear to diverge. In the triangle  $QIq$ ,  $QI : Iq :: \text{sine of } IqQ$

$IqO$  : line of  $IQO$  ; that is, since  $QO$  is parallel to  $IP$  :: line of refraction : line of incidence. If  $I$  is very near to  $O$ , the lines  $QI$ ,  $qI$ , will be very nearly equal to  $QO$  and  $qO$ , and a person being placed in the direction  $QO$  produced will conceive that the rays diverged from  $q$ , when  $QO : qO ::$  line of refraction : line of incidence.

Upon this principle we can find the actual situation of any object seen in a medium different from that in which we are, or seen through different mediums. Let  $QR$  (Fig. 13, 14.) be any object seen by a person in the medium  $ABCD$ . Then make  $QE : qE$  and  $RF : rF ::$  line of refraction to the line of incidence, and the object will appear to be at  $qr$  nearly, if the person was in the direction  $QE$  produced. Let  $O$  be the place of the person's eye in any other situation, and join  $Or$ ,  $Oq$ , then the object is seen by rays refracted within the surface  $mn$ , and  $QmO$ ,  $RnO$ , are the directions nearly of the extreme rays by which the object is visible.

Hence we perceive the reason why the bottom of a river appears to us nearer than it really is; and why an oar, partly in and partly out of the water, seems broken. Let  $Qma$  (Fig. 15.) represent an oar, the part  $mQ$  being out of, and the part  $ma$  being in the water, the rays diverging from  $a$  will appear to diverge from  $b$  nearer to the surface of the water, every point in  $ma$  will be found nearer to the surface than its real place, and the  
part

part  $ma$  will appear to make an angle with the part  $Qm$ .

On the same principle a common experiment is explained. Put a shilling into a basin, and walk back from it till the shilling is just obscured by the side of the basin; then by pouring water into the basin, the shilling appears instantly; for by what has been said above, the object, being now in a denser medium, is made to appear nearer to its surface.

As we are accustomed to see objects frequently through thin panes of glass, it may, to prevent misapprehensions on this subject, be necessary to shew what changes take place in the apparent situation of these objects from the intervention of such a medium.

Let  $ABCD$  (Fig. 15.) be a pane of glass,  $QR$  an object seen through it, whose apparent place, found by the preceding rules, is  $xr$ , and let  $Qmop$  represent the progress of one of the rays diverging from  $Q$ . Then, from what has been before observed,  $xp$  is parallel to  $Qm$ . Therefore  $qm : mo :: Qq : Qx$ ; that is, when  $m$  is very near to  $E$ ,

$$qE : EF :: Qq : Qx;$$

$$\text{or, } qE : Qq :: EF : Qx.$$

But supposing  $I : R$  to represent the ratio of the sines of incidence and refraction of a ray passing into the glass,

$$qE : Qq :: I : I - R,$$

$$\therefore EF : Qx :: I : I - R;$$

that

that is, the interval between the surfaces of the pane is to the distance between the real and apparent places of the object as the sine of incidence to the difference between the sines of incidence and refraction. For glass this ratio is nearly that of  $3 : 2$ ; therefore  $I : I - R :: 3 : 1$ , and  $Qx$  will be therefore one third of  $EF$ ; if the pane of glass is a tenth of an inch thick, an object seen through it will not appear to be a thirtieth part of an inch out of its real place; a change which is too small to be taken notice of in common life.

A ray passing through a medium bound by plane surfaces inclined to each other, is bent towards the thicker or thinner part of the medium, according as the medium is denser or rarer than that by which it is surrounded, and the place in which an object will appear to be is found by a very easy construction. Let  $ABC$  (Plate V. Fig. 16.) be a glass prism,  $QR$  an object seen through it by an observer at  $O$ . From  $Q$  draw  $QH$  perpendicular to the first surface  $AC$ , and let  $q$  be the focus of rays refracted by that surface; from  $q$  draw  $qE$  perpendicular on  $AB$ , the second surface produced, if necessary, and supposing  $q$  then to be the focus of diverging rays falling on  $AB$ , let  $t$  be the focus of rays after refraction found by the proportion before laid down, or by joining  $HE$ , and drawing  $Qt$  parallel to it. In the same manner the apparent place of  $R$  will be found, and a person at  $O$  will see the object  $QR$  apparently in  $tx$ . The point  $Q$  he sees by the





the ray  $QFGO$ , and the point  $R$  by the ray  $RLMO$ .

When the surfaces are spherical, a change is made in the apparent places of objects no less remarkable than that which we have observed in objects placed before convex or concave mirrors. To understand the reason of these appearances, it is necessary to examine the progress of a ray in the simplest cases, and thence to go on to the more difficult.

Let  $ABFD$  (Fig. 17, 18.) represent a medium rarer or denser than the surrounding medium, and bounded by a spherical surface  $AEB$ , and let the ray  $GH$  parallel to  $IE$  a ray passing through the center of the arch  $AEB$  be refracted at  $H$ , to or from the perpendicular, according to the nature of the medium. The sine of the angle  $CHG$  is to the sine of the angle  $CHI$  in a given ratio, but  $CI : IH :: S. CHI : S. CHG$ , therefore  $IH : IC$  in the given ratio of the sine of incidence to the sine of refraction depending on the nature of the mediums. The nearer  $H$  is to  $E$  the nearer will the ratio of  $IH$  to  $IC$  be to that of  $IE : IC$ , and consequently by finding a point  $I$  in the line  $CE$  produced, such that  $IE$  may be to  $IC$  in the given ratio of the sine of incidence to the sine of refraction, all the rays parallel to  $IE$ , which are refracted by the convex surface  $AEB$  (Fig. 17.) will after refraction converge to  $I$ , or a small space very near it. The greater the distance of  $H$  from  $E$ , the greater will be the distance  
of

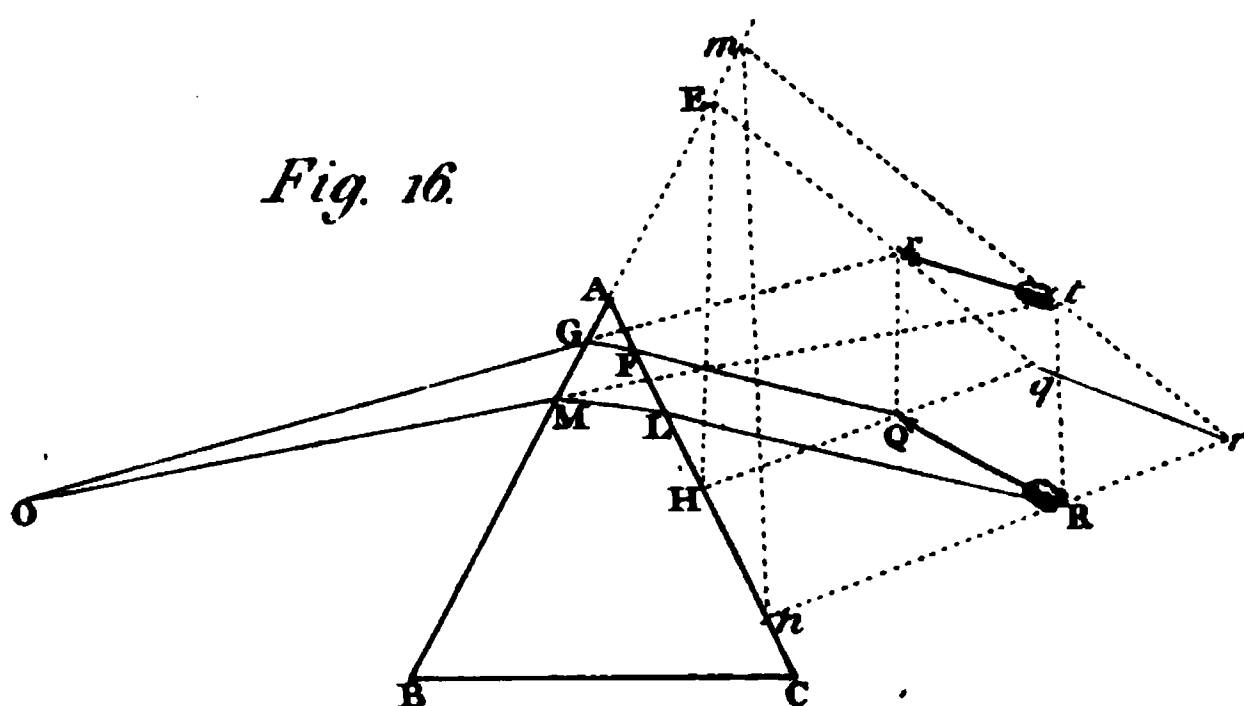
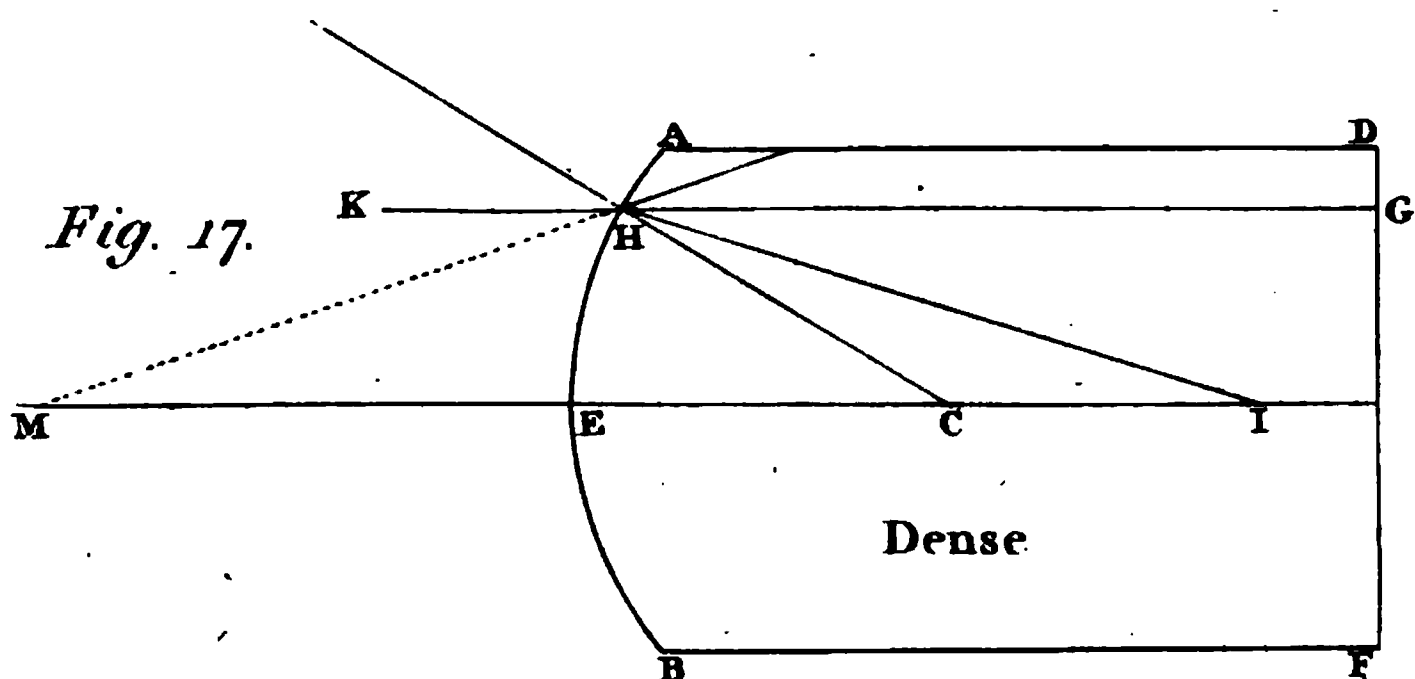
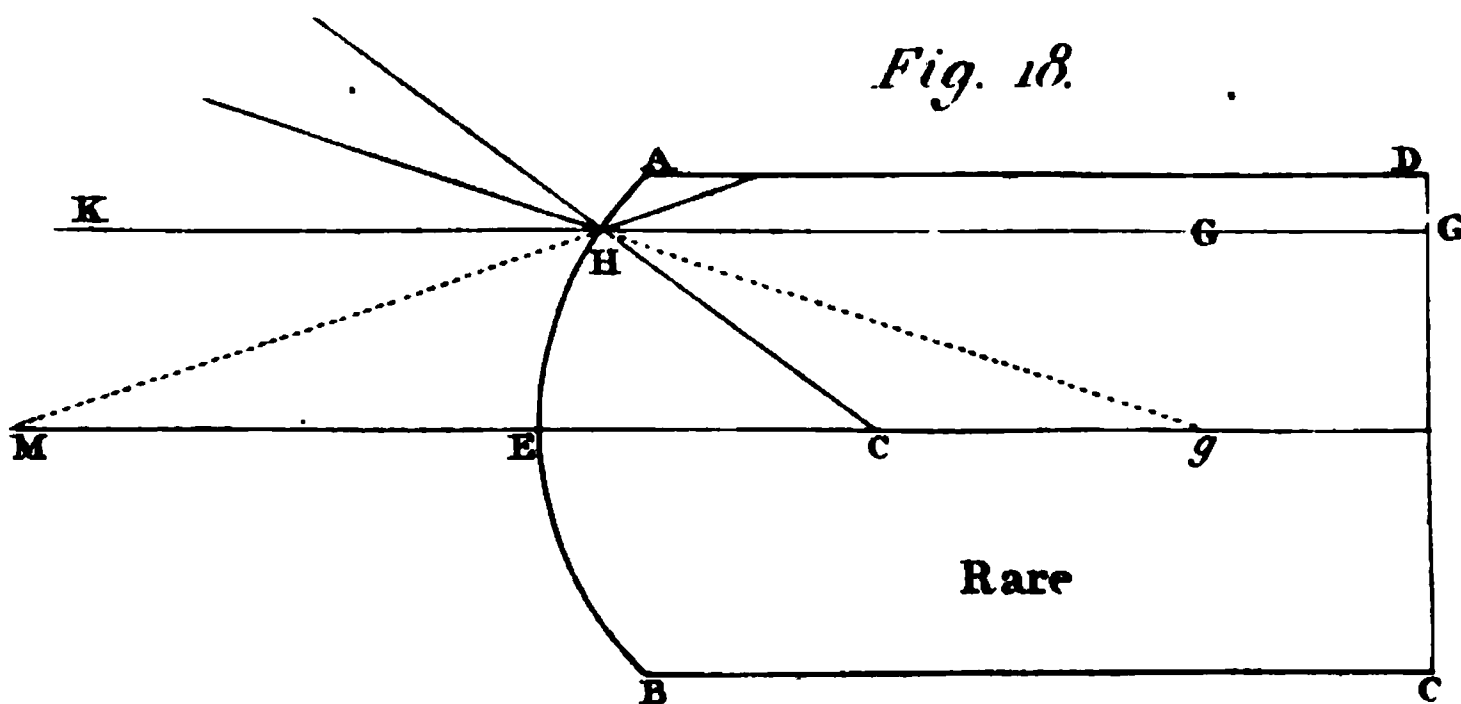
of the intersection of the refracted ray and line IC from the points I and M. This point I is called the focus of refracted parallel rays.

In the same manner M is the focus of rays coming out of the dense medium, and  $CM : EM :: \text{fine } R : \text{fine } I$ .

Parallel rays incident on the convex surface of a denser medium, or the concave surface of a rarer medium (Fig. 17.) converge after refraction; and on the contrary, if they fall on the convex surface of a rarer, or the concave surface of a denser medium (Fig. 18.) they appear to diverge after refraction. The focus of parallel rays thus found is called the principal focus.

Let Q now (Plate VI. Fig. 19.) be the focus of diverging rays incident on the surface AB of a denser medium; to find the focus after refraction draw QI an incident ray, and suppose T to be the focus of rays parallel to CQ, incident on the concave surface IEB, and make CP equal to CT, from I draw Iq parallel to CP, and q will be the focus of refracted rays. Let t be the focus of rays parallel to QC incident on the convex surface, and make Cp equal to Ct. Then since a ray parallel to Cp incident on the concave surface would after refraction converge to P, a ray diverging from P will after refraction go parallel to CP. Now the course of the ray QI is the same, whether it is considered as diverging from Q or P, therefore the direction of one of the rays diverging from Q will be in the line QIq. Suppose now the ray  
qI



*Fig. 16.**Fig. 17.**Fig. 18.*



$qI$  to be turned back, its progress will be the same as if it had diverged from  $p$ ; but all rays diverging from  $p$ , and incident on the concave surface, move after refraction parallel to  $Cp$ ,  $p$  being the focus of parallel rays incident on the other surface, therefore the ray  $pI$  must after refraction move parallel to  $Cp$ ; but its direction must necessarily be  $IQ$ , therefore  $IQ$  is parallel to  $Cp$ . We have hence two similar triangles  $QPC$ ,  $Cpq$  and  $QP : PC :: Cp : pq$ . Now if  $I$  is very near to  $E$ ,  $QP$ ,  $PC$ ,  $Cp$ ,  $pq$  will be very nearly equal to  $QT$ ,  $TC$ ,  $Ct$ ,  $tq$ , and by making as  $QT$  to  $TC$ , so  $Ct$  to  $tq$ , we shall find a point  $q$  near to which all the rays diverging from  $Q$  will by refraction be made to converge.

Hence  $QT$  varies inversely as  $tq$ ; that is, the greater the distance of  $Q$  from  $T$ , the less will be that of  $q$  from  $t$ , for  $CT$  and  $Ct$ , remain invariable in the proportion, however the position of  $Q$  may be varied.

The points  $Q$  and  $q$  are always on opposite sides of  $T$  and  $t$ .

If the point  $Q$  was at such a distance, that the rays diverging from it might be considered as parallel,  $q$  and  $t$  would coincide. As  $Q$  was brought nearer to  $T$ ,  $q$  would recede from  $t$ ; when  $Q$  and  $T$  coincide, little  $q$  will be no longer in the line  $Eq$ , but the refracted rays will now be parallel. As  $Q$  moves from  $T$  to  $E$ ,  $q$  appears at a great distance from  $E$  on the same side of the surface with  $Q$  and overtakes it at  $E$ .

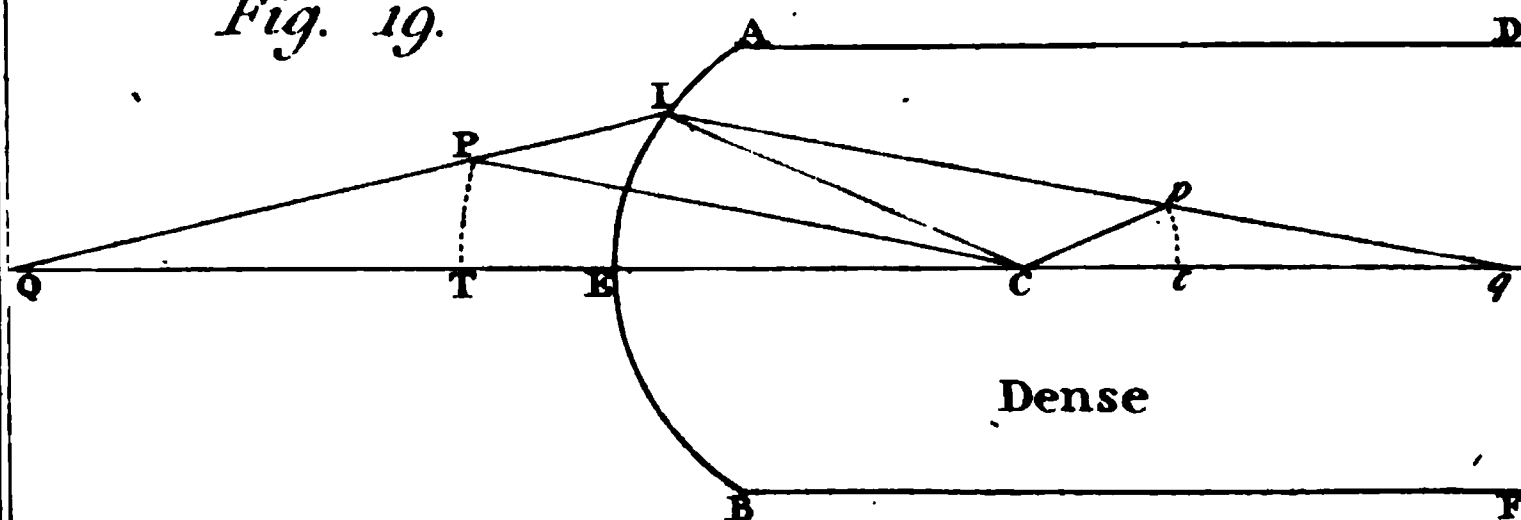
Diverging

Diverging rays incident on the convex surface of a denser medium, or the concave surface of a rarer medium, are made to converge or diverge according to the situation of their foci with respect to the principal focus. When they are incident on the convex surface of a rarer medium, or the concave surface of a denser medium, their progress may be seen in Figures 20, 21.

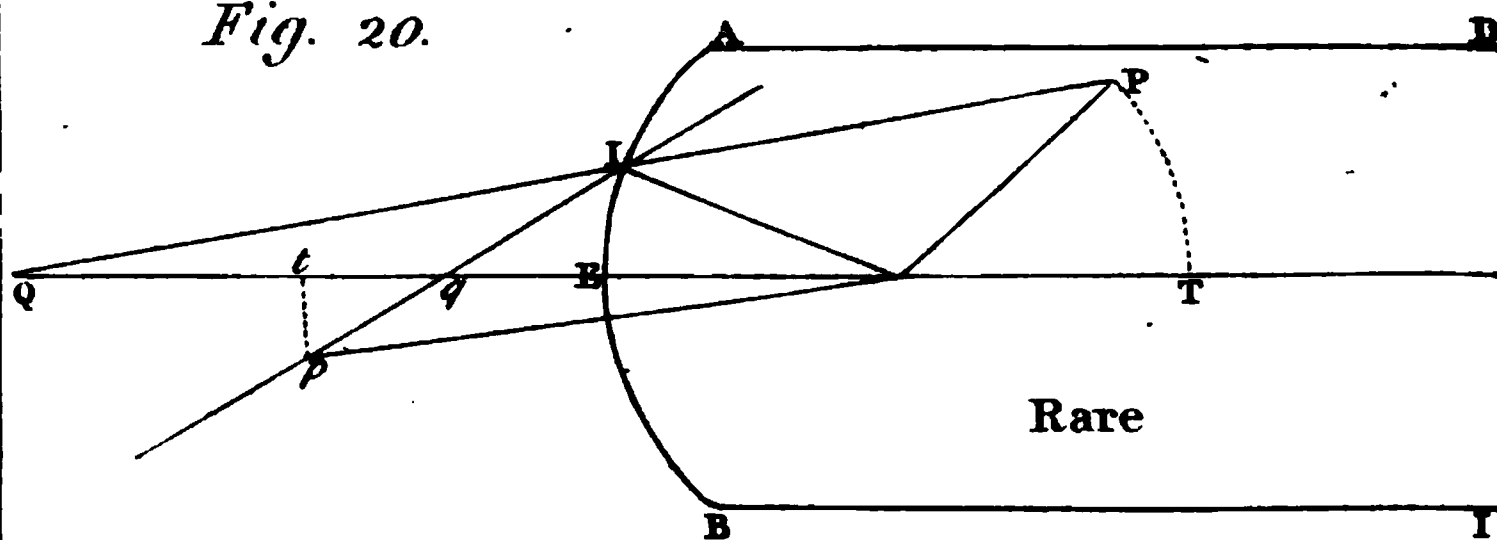
The ray  $QI$  diverging from  $Q$  will be affected in the same manner as if it was supposed to converge to  $P$  the principal focus of rays incident on the concave surface; but a ray converging to  $P$ , will by refraction of the convex surface be made to proceed in a direction parallel to  $CP$ , therefore  $qI$  will be parallel to  $CP$ . Again, a ray incident on concave surface converging to  $q$ , may be considered as converging to  $p$ , the focus of parallel rays on the convex surface, and therefore by refraction of the concave surface, it will be made to proceed in a direction parallel to  $Cp$ . Hence as before the triangles  $QPC$ ,  $qpC$  are similar, and the same proportion is deduced  $QT : TC :: tC : tq$ .

Rays therefore diverging from any point, and intercepted by the convex surface of a rarer or concave surface of a denser medium will by refraction be made always to diverge more. Upon the same principles, and in the same manner, the effects of spherical surfaces on converging rays is shewn, which are exactly opposite to those of diverging rays, and a learner may profitably exercise himself by trying the effect on paper on rays converging or  
diverging

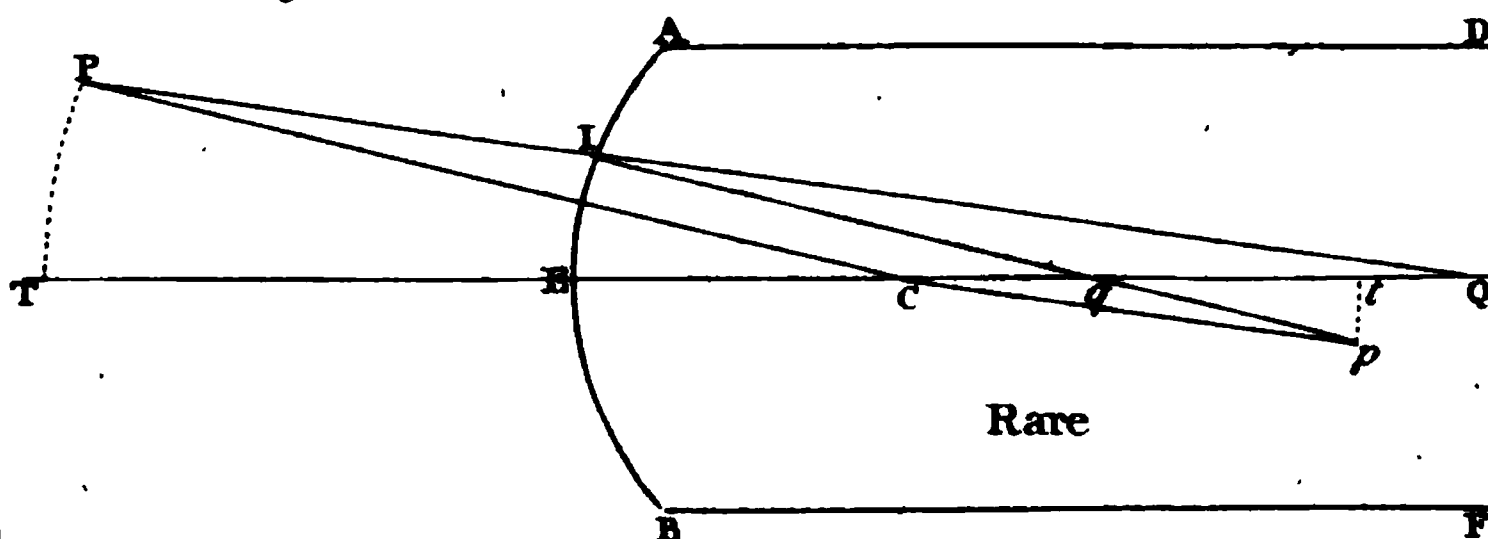
*Fig. 19.*



*Fig. 20.*



*Fig. 21.*





diverging, refracted by the convex or concave surface of different mediums.

Having thus discovered the progress of rays of light diverging from any point, and intercepted by a refracting spherical surface, we shall find no difficulty in accounting for the apparent places of objects seen in different mediums bounded by spherical surfaces.

Let  $QM$  (Plate VII. Fig. 22.) be an object in a glass medium, and  $q$  the focus of refracted rays diverging from  $Q$ ,  $m$  the focus of refracted rays diverging from  $M$ . Then  $qm$  will be the image of  $QM$ . Let  $O$  be the place of the spectator, and join  $Oq$ ,  $Om$ , then  $rs$  is the part of the glass through which he sees the object, and  $QrO$ ,  $MsO$  are the extreme rays by which it is seen. Let a dense medium be now bounded by a convex surface, fig. 23. and an object  $QM$  be at such a distance from it, that its image shall be  $qm$ , and the place of the spectator  $O$ . He will see only part of the object corresponding to  $um$ , and through the part of the surface  $As$ , and the object will appear to him inverted.

If the eye is placed nearer the surface than the image is, the object will appear confused; for the rays striking the eye will then be converging to a place behind it: but as I have been rather prolix on this subject in the case of objects before reflecting mirrors, it will not be necessary to pursue it farther, as on the same principles the reader will with ease determine the part of an object seen in

any medium, bounded by a spherical surface, the part of the surface through which it is seen, and the rays by which it is seen. The truth of some of these principles may be experimentally shewn by objects placed in glass vessels, with concave or convex surfaces, filled with water, but as we cannot form a medium rarer than that in which we live, the cases of objects placed in a rarer medium must remain established on the fixed basis of mathematical truth here laid down. If we were indeed to rarify the air in a hollow glass globe, we might observe, perhaps, the changes made in the apparent places of an object, according to the successive degrees of rarefaction; but still the object would be seen through one medium much denser than the surrounding atmosphere, and before we can examine the apparent situation of an object placed in one medium, which is separated from another by a medium of a different density from either, and bounded by a concave and convex surface, we must endeavour to account for the appearances which are daily before our eyes, namely, the changes made in the apparent places of objects by the interposition of a dense substance bounded by spherical surfaces.



## C H A P. V.

## O F L E N S E S.

*Glasses used to correct and assist the Sight.—Different Forms of Lenses.—Effects resulting from these different Forms.—Double convex and concave Lenses.—Plano-convex and concave Lenses.—How to determine the Focus of a Lens.—Focus of Rays diverging from a Point, and intercepted by a Lens.—Focus of a Sphere.*

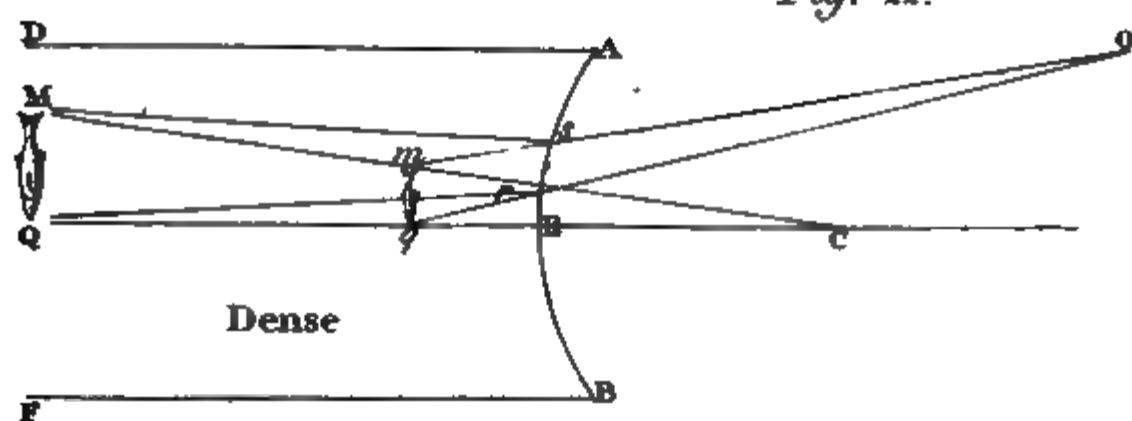
**I**N common life, persons whose sight is bad make use of glasses to correct the defect in their eyes, and these are in general thin pieces of glass, the surfaces of which are both concave, or both convex, and equal segments of a sphere. Such a glass, we have already seen, is called a lens, which is not, however, confined to these two shapes; for some have one surface plane and the other concave, some have one surface plane and the other convex, others have one surface concave and the other convex; but the properties of all these glasses will be easily understood by any person who has duly considered the effect of a single spherical refracting surface on the rays of light.

It is necessary to premise, however, that in investigating the properties of a lens, we consider its thickness as very inconsiderable, and that in every

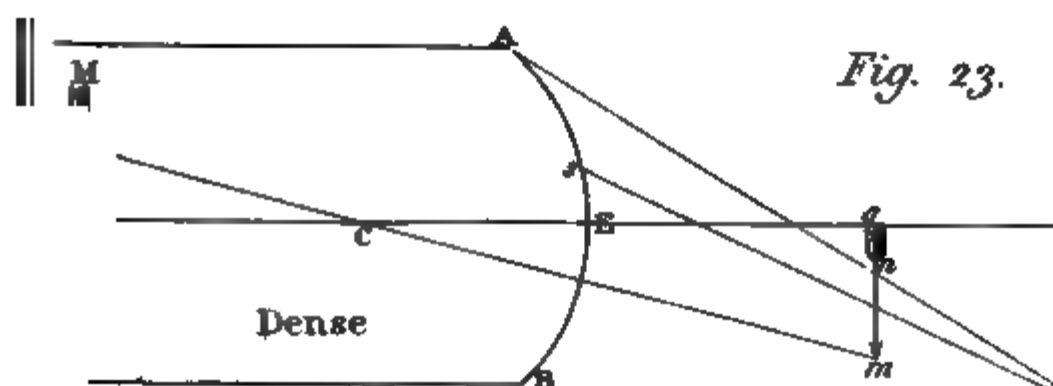
species there is a point, through which if a line is drawn in any direction, and intersected by the surfaces of the lens, a ray refracted by one surface into this line will, after the second refraction, emerge parallel to its first direction.

Let  $A I o B n$  (Plate VII. Fig. 24, 25.) represent a convex or concave lens, the radii of whose surfaces are equal, and draw  $C I$ ,  $C i$  from the centers  $C$ ,  $c$ , parallel to each other, and join  $I i$ . Suppose now  $I i$  to be a ray of light within the lens refracted by both surfaces at  $I$  and  $i$ . Since the radii are parallel, the angles of incidence are equal, and consequently the angles of refraction are equal, and the refracted rays must make equal angles with the incident ray  $I i$ , that is, they must be parallel to each other. A ray, therefore, incident on  $I$ , and proceeding in the direction  $I i$ , will, after refraction at  $i$ , proceed in a direction parallel to its first direction. In the same manner any other ray incident on one surface, and proceeding in the line joining two parallel radii, will, after refraction at the second surface, emerge parallel to its first direction. But the line joining two parallel radii will always pass through the same point  $m$ ; therefore all rays passing through this point  $m$  will, after refraction at the second surface, proceed parallel to the direction, which they had before the first refraction. This point  $m$  is the center of the lens, and in the two cases before us it bisects the thickness of the lens; for since the triangles  $C I m$ ,  $c i m$  are similar,  $C I : c i :: C m : c m$  and as  $C I$  and  $c i$  are equal  $C m$  and  $c m$  are equal, and

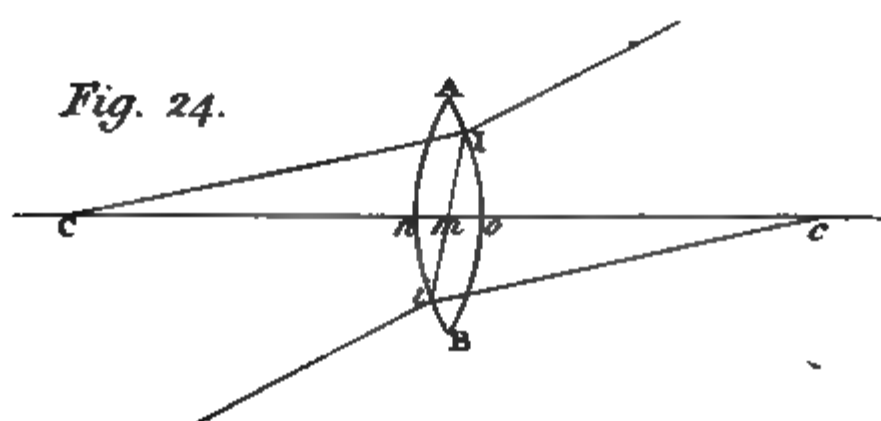
*Fig. 22.*



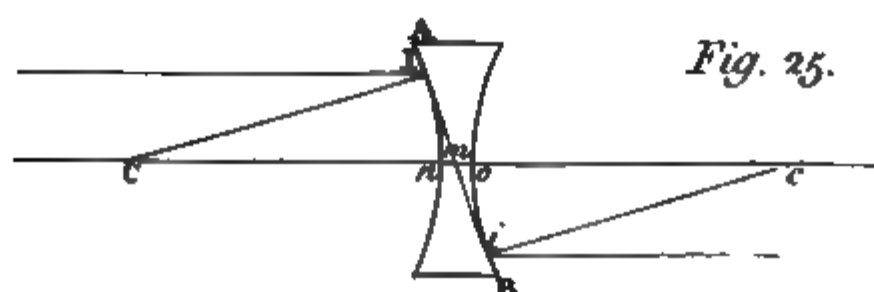
*Fig. 23.*



*Fig. 24.*



*Fig. 25.*





and consequently  $nm$  and  $mo$  are equal. If the radii were not equal, the center of the lens is nearest to that surface whose radius is the least, and its place may be accurately found by the preceding proportion.

In Plate VIII. Fig. 26, 27. represent two lenses, the one with a plane and a convex surface, the other with a plane and a concave surface. In both cases the center of the lens will be at  $n$  in the spherical surface, for the point may be considered as in the tangent to the circle at  $n$ , which is parallel to  $AIB$ , therefore the ray  $Ii$  makes equal angles of incidence at the points  $I$  and  $i$ , and consequently the angles of refraction will be equal. From the proportion also discovered in convex or concave lenses, the same truth is evident; for as we increase the radius of  $AIB$ , the point  $m$  approaches nearer to  $n$ ; and as this radius may be increased without limit, the distance of  $mn$  may be decreased without limit, so that evidently the nearer the circle approaches to a plane figure, the nearer will be the approach of  $m$  to  $n$ .

Plate VIII. Fig. 28. represents a lens with one surface concave the other convex, in which case the point  $m$  will be without the lens.

Having found the centre of a lens, we are next to find its principal focus or point, from which parallel rays, after refraction, appear to diverge, or to which they converge. Let  $AB$  (Plates VIII. IX. Fig. 29, 30, 31, 32, 33, 34) represent a lens, whose center is  $E$ , and the centers of the surfaces  $R$  and  $r$ , and let  $qEG$

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be drawn parallel to the incident rays; then as the directions before and after refraction of a ray passing through the center of a lens are parallel,  $q$  E G will represent the course of one of the incident rays without sensible error. Parallel to E G draw B R, and in B R produced find the focus V of parallel rays incident on the surface B; therefore by the first refraction the parallel rays are made to strike the second surface A, converging to the point V. Join  $r$  V. Then one of the rays, which after the first refraction moved within the glass in the direction  $r$  A, will pass through the second surface A, without any refraction, in the direction A V, since  $r$  A is perpendicular to the second surface. But E G is the course of another ray also after the second refraction, and G, the point of intersection of these two rays, will be the focus of the lens, near to which all the other rays will intersect each other. For all the rays incident on the second surface converging to the point V, by what has been proved of rays refracted by a single spherical surface, will be made to converge to a point between A and V. We have found the point G, as above, for a double convex lens, but the same mode of reasoning applies to other lenses, and a single inspection of the figure will shew whether the rays converge or diverge after the first refraction.

With E as a center, and E G as radius, describe the arc G F. Then if the direction of the parallel rays is changed, the focus will always be in the arc G F, and if the incident rays are parallel to  $r$  R, the

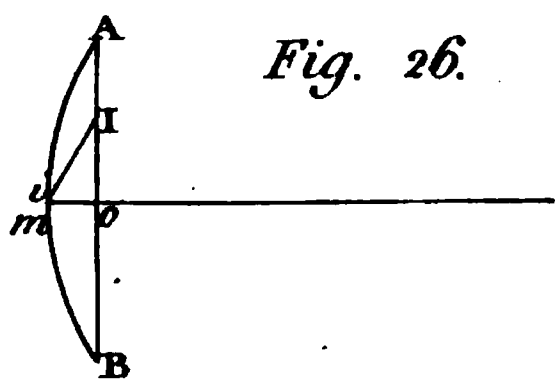


Fig. 26.

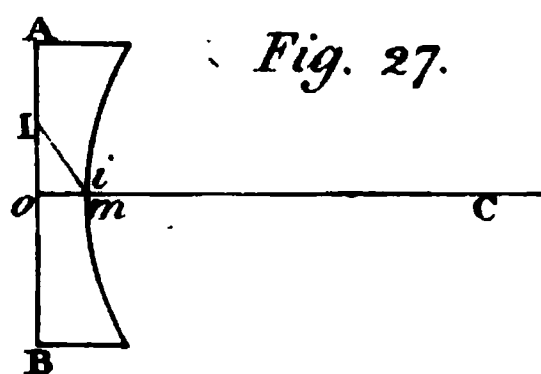


Fig. 27.

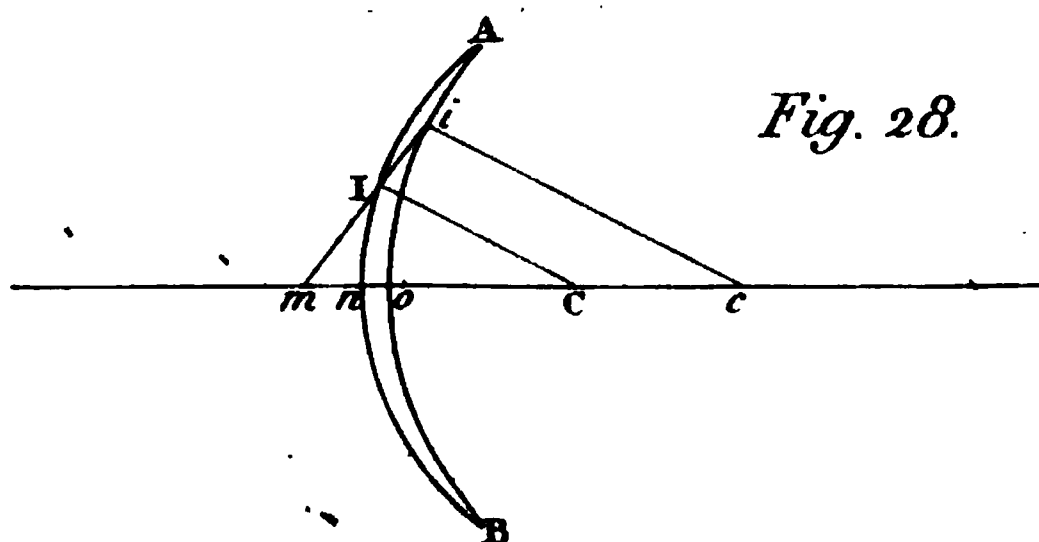


Fig. 28.

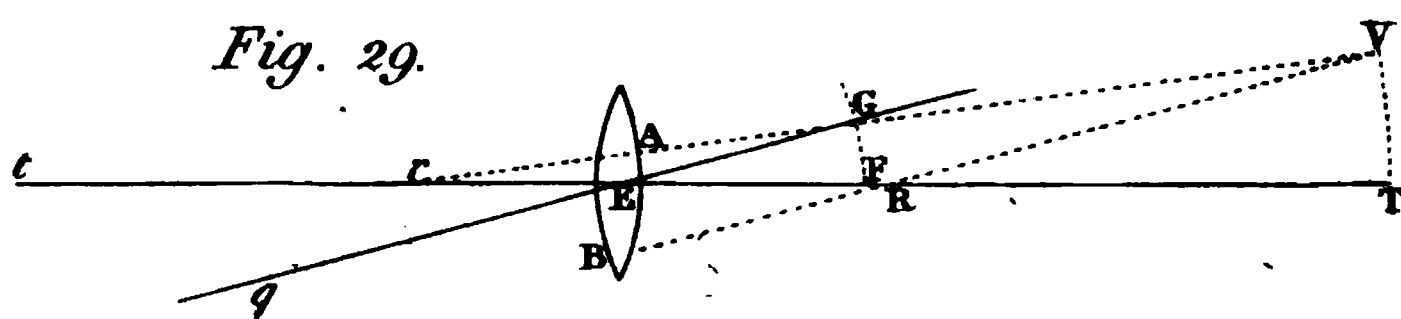


Fig. 29.

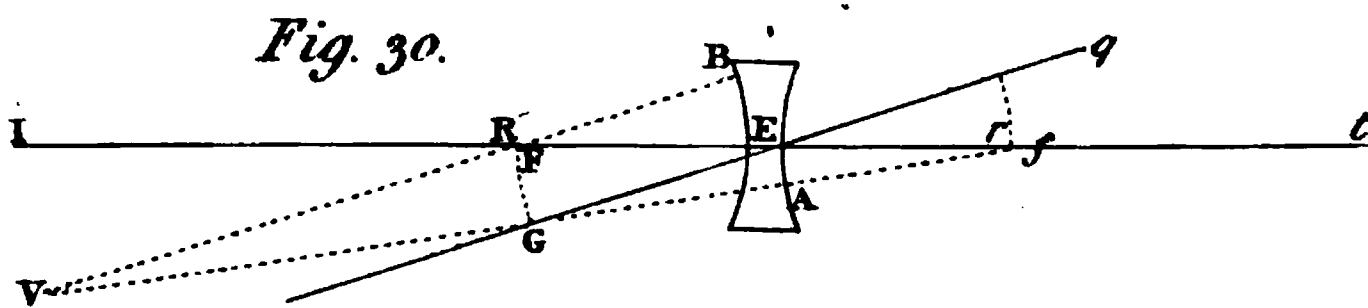


Fig. 30.

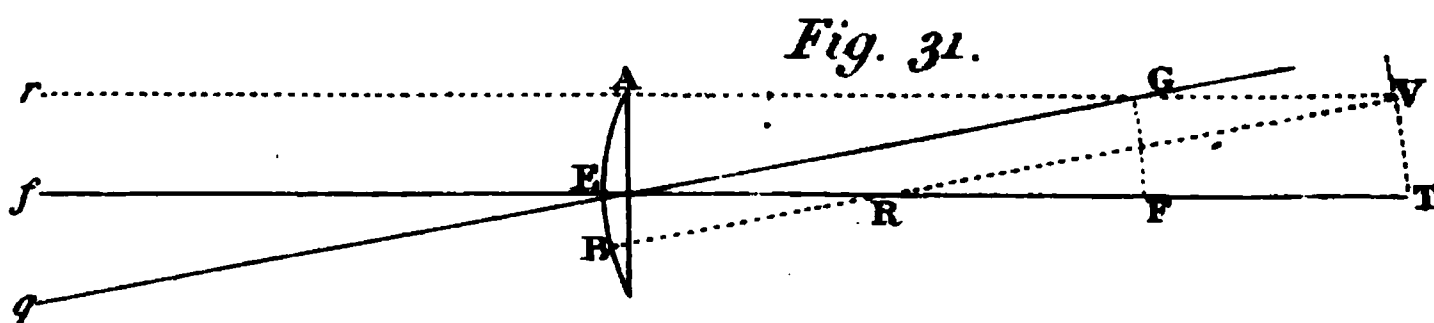


Fig. 31.





the axis of the lens, the principal focus is in F. A double convex and plane convex lens make parallel rays to converge; a double concave and plane concave make them diverge. A lens with a concave and convex surface make them converge or diverge, according as the surfaces do or do not intersect each other, or in general it may be said of all these lenses, that the parallel rays converge or diverge after refraction according as the middle of the glass is thicker or thinner than its extremities.

Upon the same principles also may be found the foci of lenses, supposing them to be composed of substances rarer instead of denser than the surrounding medium.

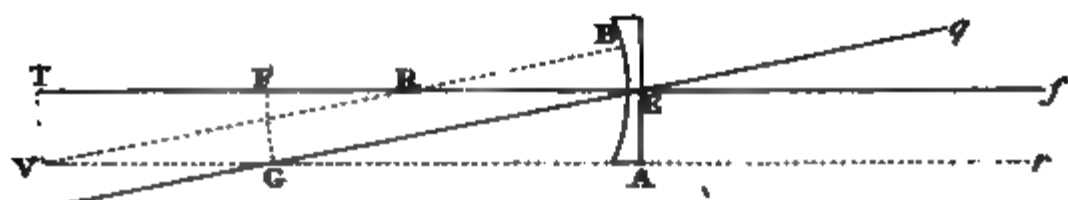
Having found the principal focus of a lens, we shall with the same ease find the focus of rays diverging from a point, and intercepted by a lens, as we did when they were intercepted by a single surface. Let Q (Plate IX. Fig. 35.) be the focus of diverging rays incident on the lens A B, and let F,  $f$ , be the principal foci of rays incident on the surfaces B or A, in a contrary direction, and let  $Qi$  represent an incident ray. With E as a center, and E F radius, describe the arc F G intersecting  $Qi$  in G, join E G, and draw A  $q$  parallel to E G, then with E as a center, and E  $f$  radius, describe the arc  $f g$  intersecting  $iq$  in  $g$ , and join E  $q$ . The ray  $Qi$  will be affected in the same manner, whether it is considered as diverging from Q or G; but since rays parallel to E G, incident on the surface B, are by the refraction of the lens made to

converge to  $G$ , a ray diverging from  $G$  will, after the refraction of the lens, move parallel to  $EG$ ; therefore the ray  $Qi$  will be made by the lens to move in the direction  $Aq$ . Again, if the ray was turned back, it might be considered as diverging from  $g$ , and by the lens it would be made to move in the direction  $iQ$ , parallel to  $Eq$ . Hence we have two triangles,  $QGE$ ,  $EGq$ , similar to each other, and  $QG : GE :: Eg : gq$ ; that is, the nearer  $i$  is to  $E$ , the nearer will this proportion be to that of  $QF : FE :: Ef : fq$ , a proportion similar to that which we found before with single surfaces.

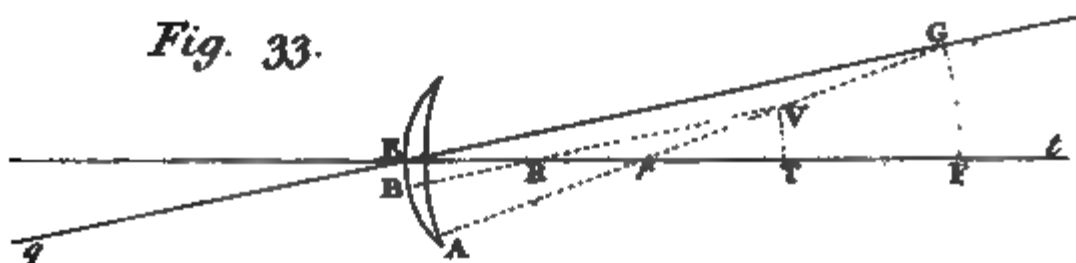
The points  $Q$  and  $q$  will be on the opposite sides of their respective foci. The greater  $QF$  is, the less will be  $qf$ , and *vice versa*; and the apparent places of objects viewed through these glasses will be found in the same manner as with single surfaces. It will be sufficient therefore only to refer the reader to Plates IX. X. Fig. 36, 37. which he will easily understand without farther explanation.

The principal focus of a sphere is found with the same facility as that of a lens. Let  $M$  (Plate X. Fig. 38.) be the principal focus of rays incident on the convex surface  $AO$ , then bisect  $MD$ , in  $I$ , and  $I$  will be the principal focus of the sphere. For let the ray  $GA$  be refracted by the convex surface to  $B$ , and at  $B$  by the concave surface to  $I$ , and let  $IB$ ,  $GA$  produced meet each other in  $K$ . Now suppose that the ray  $AB$  within the sphere emerged at both places  $A$  and  $B$ , then since the

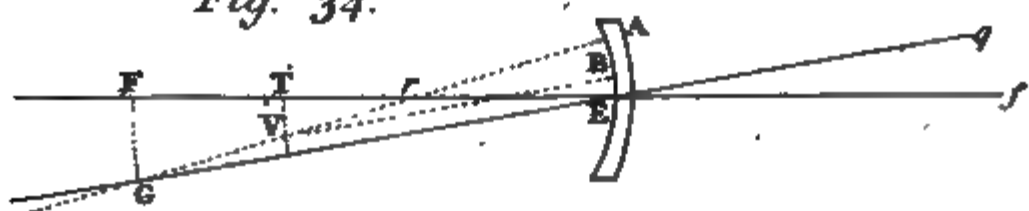
*Fig. 32.*



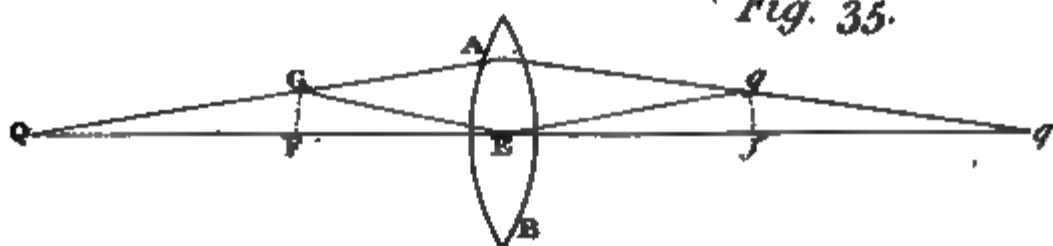
*Fig. 33.*



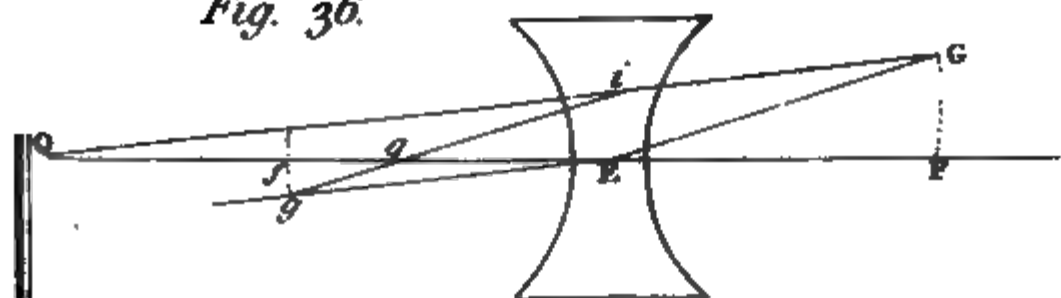
*Fig. 34.*



*Fig. 35.*



*Fig. 36.*





angles of incidence  $CAB$ ,  $CBA$  are equal, the angles of refraction, and the difference between the angles of incidence and refraction, will be equal; therefore  $KAB$  is equal to  $KBA$ , and  $KA$  equal to  $KB$ ; but the triangle  $BIM$  is similar to the triangle  $KBA$ , therefore  $IB$  is equal to  $IM$ ; and as  $B$  approaches to  $D$ , the nearer will  $IB$  be equal to  $ID$ , that is,  $ID$  to  $IM$ , and consequently the principal focus will bisect  $DM$ , or the least distance of the principal focus of rays refracted by the convex surface from the sphere.

Having thus found the principal focus of the sphere, I shall leave the reader to find the apparent places of objects seen through it, as the mode to be pursued has already been sufficiently described, and the proportion is similar to that discovered in the consideration of lenses,

## C H A P. VI.

## OF VISION AND OPTICAL GLASSES.

*The Eye described as an optical Instrument.—Defects of the Eye.—Short and weak Sight.—The former remedied by double concave, and the latter by double convex, Glasses.—How the Faculty of seeing correctly is acquired.—Apparent Magnitude depends on the Distance of Objects.—Visual Angle.—In what Manner Glasses assist the Sight.*

**T**HE structure of the eye will be considered in another place \*; it will be sufficient therefore at present to treat it as a simple lens, which has the power of refracting the rays of light, incident upon it, on the retina, whence we derive all our ideas of sight, and by repeated experience correct the errors which by that organ alone might have been produced. Let  $AB$  (Plate X. Fig. 39.) represent a section of the eye,  $MN$  being the pupil,  $AqpB$  the retina or optic nerve expanded over the internal surface of the eye, and let  $qp$  be the image of  $QP$  made by the lens  $MN$ . The action produced on the part of the retina  $qp$  occasions a sensation, from which we derive by the sight our knowledge of external objects.

\* See Book IX. Chap. 41. Sense of Sight.

Now

Now if the lens MN was fixed, the image of two objects at different distances from the eye would not fall on the retina, and therefore it is wisely provided by our Creator, that we should have the power of adapting the lens to the distance of the object, so that its image should be always upon the retina. This is the case with the generality of mankind; but all persons have not this power; for the eyes of some are so constructed, that the rays of light either converge too soon or too late; that is, the image is made in some place between the retina and the pupil, or it would be made behind the retina, if the retina was removed; hence these persons cannot see objects distinctly, and to remedy these defects glasses are used, which in the one case make the rays diverge, and in the other case make them converge. Thus for short-sighted persons as they are called, double concave glasses, for long-sighted persons, double convex glasses are used. By means of the concave glasses the rays incident on the eye are made to diverge more; and consequently the eye, which before made them converge too soon, will now be able to form the image on the retina. By the convex glasses the rays are made to converge, and consequently the image, which would otherwise have been behind the retina, is now formed in its proper place on the retina.

It is a long time, probably, before the child is able to use all the muscles by which the pupil is contracted or expanded, so that the image should  
fall

fall exactly upon the retina, and then the ideas formed by the sight must be exceedingly inaccurate. At first all objects will appear equally to touch the eye, and the apparent magnitude of the object will depend on the part of the retina covered by the image. By degrees these ideas are corrected, and the hands instruct, after some difficult experiments, the eye. The child discovers that objects are at a distance from its body, and that such as make the same angle at the pupil are not always of the same real magnitude; hence it learns by degrees to combine together the angle under which an object is seen and the distance, and, according to its future employments in life, these ideas will be combined together with greater or less accuracy. The judgment of one person, accustomed to distant objects, will be very correct, while a person employed in the nicer works of art will be continually deceived in looking at the same distant objects, and the contrary.

An object will affect us differently, I have said, according to the angle under which it is seen, and its distance. First, if several objects are seen under the same angle, they would, to a person whose judgment was not better informed, appear to be of the same size, for they would make the same image upon the retina.

Again, if several objects were at the same distance from the eye, the magnitude of the visual angles, and the small images on the retinas, would depend on the magnitude of the objects.

Hence



Hence the real magnitude varies as the distance, when the visual angle is the same; and it varies as the visual angle, when the distance is the same; therefore the real magnitude of an object varies as the visual angle, or apparent magnitude multiplied into the distance.

By repeated experiments the sight of every person might be much improved. Suppose a yard to be placed at a certain distance from the eye, and the apparent magnitude of the yard and the distance to be so impressed on the spectator's mind, that on setting it up in any place he could walk back and fix exactly on the spot which should be at the first given distance from his eye to the yard, he might, by degrees, accustom himself to measure objects so accurately, as to be very little liable to mistakes in any of his calculations. What he could do by observation, we do by theory. Thus when the distance of an object and the angle under which it is seen are given, we can very nearly tell its real magnitude. Let  $QP$  (Fig. 40.) be the object,  $O$  the place of the spectator, at the distance of one hundred rods, and the angle under which it is seen thirty degrees. Then suppose  $RS$  to be a pole, exactly a rod high, erected perpendicularly at a rod's distance from  $O$ , and note the angle under which it is seen. Then  $QP : RS :: QOP \times OQ :: ROS \times OR$ ; let  $ROS = a$ ,  $\therefore QP : \text{one rod} :: 30^\circ \times 100 : a \therefore QP = \frac{30 \times 100}{a}$

By the same proportion from the real and apparent

rent magnitudes we can find the distance, or from the real magnitude and the distance find the apparent magnitude.

$$\text{For since } QP : RS :: QOP \times OQ : ROS \times OR, QP : 1 :: QOP \times OQ : a \therefore OQ = \frac{a \cdot QP}{QOP} \text{ and } QOP = \frac{a \cdot QP}{OQ}.$$

To see any object it has been observed (Fig. 39.) that an impression must be made upon the retina; but to the eye, as to the other senses, it happens, that an impression does not always produce a sensation. There is an angle  $qMp$  of a determinate magnitude\*, which varies indeed in the eyes of different persons, but is such that any object making a less angle in the pupil does not produce a sensation on the retina of such a nature that a person can have a determinate idea of the object. This angle is in general about half a minute; and each person may discover the strength of his sight by taking an object of a determinate length,

\* If the distance of any object from the eye is sufficiently great for the rays to fall nearly parallel on the pupil, the same object is seen more enlarged and distinct the nearer it is brought to the eye, because the image of any object on the retina will be greater or less in proportion to its apparent magnitude: when the object is too near the eye it continues to be enlarged, but is confused. The least distance is about six inches.

The eye is capable of distinguishing objects that subtend an angle of half a minute of a degree, in which case the image on the retina is less in breadth than the  $\frac{1}{180}$  part of an inch, and the object, supposing it six inches distant, about the  $\frac{1}{120}$  part of an inch broad. And all smaller objects are invisible to the naked eye.

and

Fig. 37.

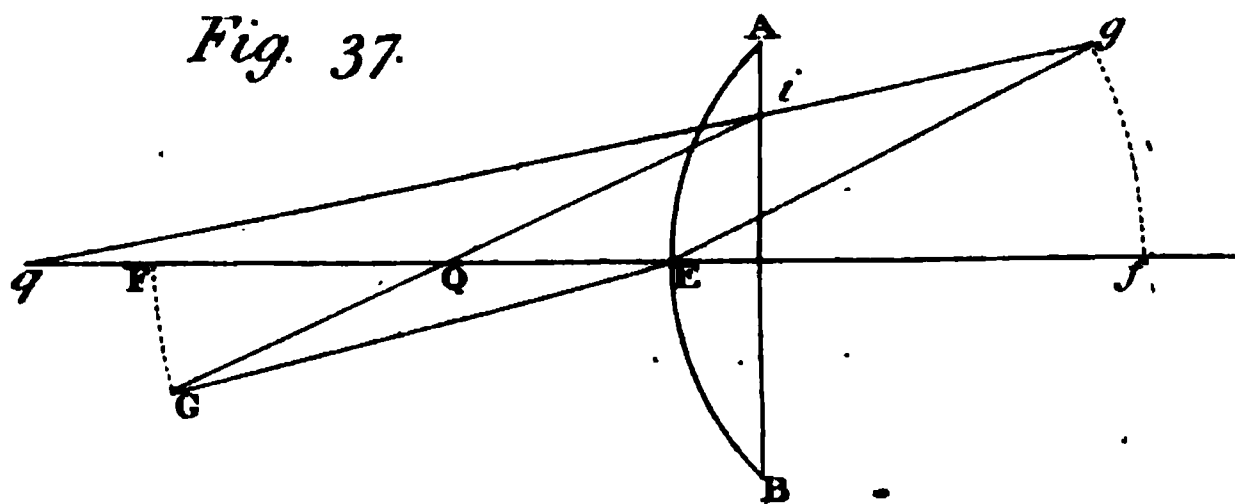


Fig. 38.

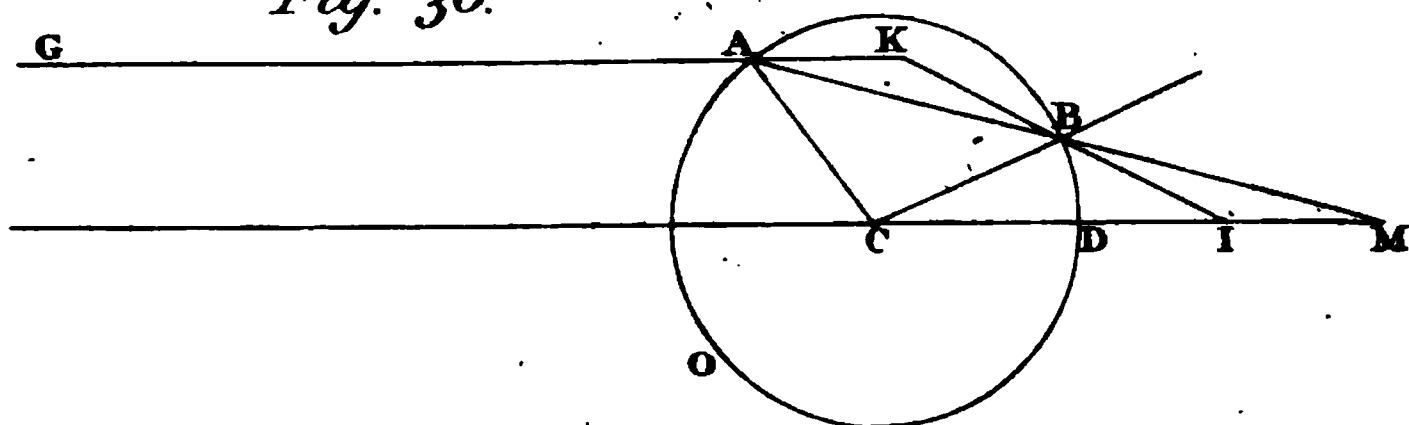


Fig. 39.

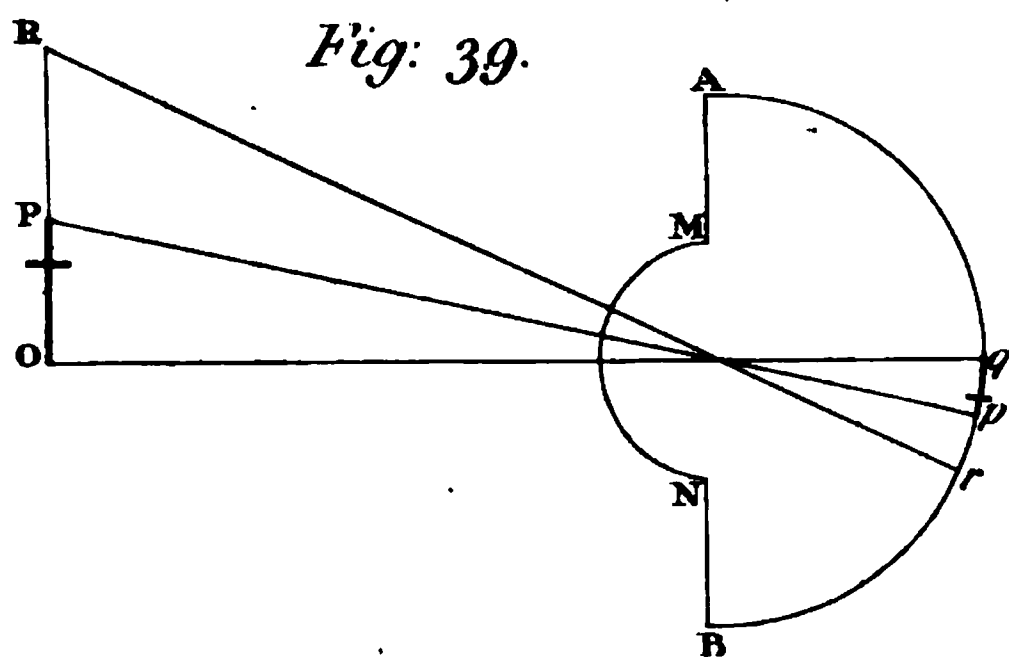
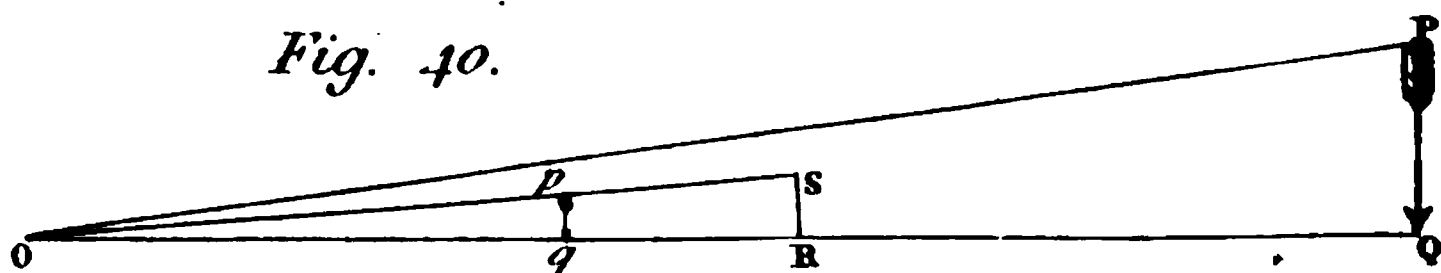


Fig. 40.





and removing it to such a distance that it shall just cease to be visible, or appear only as a point. Let  $QP$  (Fig. 40.) be carried to that distance, then measure  $OQ$ , and say, as  $OQ : QP :: \text{radius} : \text{tangent of } QOP$ , and the angle  $QOP$  will be found, or the least angle under which an object is seen.

When objects are beyond that distance, they consequently are invisible to us; and if by any art we can make them appear as if they were within this distance, they will then appear to us as other objects seen under the same angle, and at the same distance. Upon this principle depend many of the effects produced by glasses and telescopes, which I shall consider first in the simplest cases.

A person at  $O$  (Fig. 40.) can see distinctly, we will suppose, an object placed at the distance  $Oq$ , but if it is removed beyond that distance his vision is confused. Let an object be placed at the distance  $OQ$ , by means of a double concave glass, which makes the rays diverging from  $Q$  to appear to diverge from  $q$ , the object will be seen distinctly. On the other hand, if a person can see distinctly all objects at the distance  $QP$ , but none within that distance, by means of a double convex glass, which makes the rays diverging from  $qp$  to appear to diverge from  $QP$ , he will see the object  $qp$  distinctly. To find then by what sort of lens an object is to be seen at any distance, we must take into consideration the distance of the object, and the distance of distinct vision, from  

4
which

which it will be easy to find a lens of such a focal length as will make the object appear at the distance required.

For in Plate XI. Fig. 41, 42, the triangles  $Q A q$ ,  $E g q$ , are similar; therefore,

$$Q A : Q q :: E g : E q, \text{ or }$$

$$Q E : Q q :: E f : E q;$$

$$\therefore E f = \frac{Q E \times E q}{Q q}$$

That is, the focal length of the glass is equal to the rectangle under the distances of distinct vision and the given object divided by the difference of these distances.

If in the case of short-sighted persons the object is at such a distance that the rays coming from it to the eye may be considered as parallel,  $Q E$  and  $Q q$  may be considered as equal without any material error, and the focal length of the glass will then be equal to the distance of distinct vision.

By want of attention in the choice of glasses, a defect in sight may be considerably increased, for the eye may be strained to an accommodation with the glass. Short-sighted persons, as they advance in years, are often found to improve in sight; long-sighted persons, on the contrary, find their sight impaired by age. For the convexity in the pupil of both diminishes with years\*; in one case it was too great,

\* This is the generally received opinion, but from some observations lately communicated to the world in the *Philosophical Transactions*, by Dr. Hufsch, there is reason to believe, that the

great, and consequently the diminution was beneficial; in the other case it was already too small, and the diminution must be consequently prejudicial.

With a single glass the defects in sight, with respect to many objects either too near or at too great a distance, for the persons labouring under them, are remedied; but it has been before observed, that there is a certain angle to every person, which limits his sight, and consequently objects making an angle less than that to his eye must be indistinctly perceived. The art of man has discovered a remedy, in a great degree, to this imperfection, and by means of a combination of glasses has opened a wide field for his researches into the wonders of nature; he can now trace the limbs of an insect invisible to the naked eye, or he can make the celestial objects appear to him as if their distance had been on a sudden diminished by many millions of miles.

the convexity and concavity are not changed, as was generally imagined, but that the muscles of the eye grow weaker, like other muscles, by age, and consequently are not able, as in early life, to vary the distance between the retina and anterior surface of the eye, so as to make it correspond to the distance of the object. This question will doubtless occupy the attention of the anatomist and philosopher.

## C H A P. VII.

## VISION THROUGH TELESCOPES AND MICROSCOPES.

*Principles on which these Instruments are constructed.—Defects.—Telescope of Galileo.—Microscope.—Reflecting Telescope.—Camera Obscura.—Magic Lanthorn.*

LET QP (Plate XI. Fig. 43.) represent a very distant object, and let the rays coming from it, before they fall upon the eye, be intercepted by two convex lenses, placed at a distance from each other equal to the sum of the focal lengths. The lens AB is called the object-glass, from its being opposed to the object; CD the eye-glass, from its being nearest to the eye. Since the object is at a very great distance, the image made by refraction, qp, will be made at a distance from the object-glass equal to its focal length, and consequently the image is distant from the other glass exactly its focal length, and the rays diverging from any point of the image will, after refraction by the eye-glass, move parallel to the line drawn from that point through the center of the glass. The progress of the rays then, by which the object is seen, is easily traced. A ray Pb will be refracted by the object-glass in the direction PA pD, and by the eye-glass in



in the direction  $dO$  parallel to  $pE$ . The angle, therefore, under which the image is seen, is equal to  $qEp$ , and the angle by which the object would have been seen by the naked eye is equal to  $qFp$ ; consequently the magnitude of the object seen by the naked eye is to its magnitude, seen through the glasses, as  $qFp$  to  $qEp$ , that is, as  $qE : qF$ , or as the focal length of the eye-glass to the focal length of the object-glass.

By this simple combination of glasses an object appears inverted; but this is of no consequence to astronomers, and for objects on land several contrivances are used to rectify this appearance.

The quantity of the object visible depends upon the magnitude of the eye-glass. Let  $Ap$  represent an extreme ray refracted by the object-glass; if the eye-glass is of such a magnitude as to intercept it, the whole of the object will be seen; if the eye-glass is too small for this purpose, join  $DA$ ,  $CB$ , the extremities of the lenses, and the part of the image cut off by these lines will shew the proportional part of the object which is invisible.

Since the focal lengths of two lenses are susceptible of any proportion whatever, it might seem that nothing more was necessary than to take two lenses of determinate focal lengths to make us intimately acquainted with the most distant of the heavenly bodies; but after a certain length the difficulty of managing these glasses becomes insurmountable; and for distant objects on the earth, when the mag-

nifying power is more than a hundred, the vapours on the earth would render vision obscure.

The breadth of the object-glass is of no consequence as to the magnifying power, for whatever it may be, the image will be equally formed at the distance of its focal length; but the brilliancy of the image will be increased by the breadth, as a greater number of rays will then diverge from every given point of the image.

To make the image appear erect, two other convex lenses are required, of equal focal lengths. The rays emerging from the eye-glass are intercepted by the first of these lenses, and are made to converge to points at the distance of its focal length; thence they diverge, and being intercepted by the other lens at the distance of its focal length, they are made to proceed parallel to the lines drawn from each point through the center of the lens. Thus the first image of  $QP$  (Fig. 44.) is  $qp$ , the second  $KI$ . The apparent magnitude of the object is not changed by these glasses, and depends, as before, on the focal lengths of the object-glass and lens nearest to it. The brilliancy of the object, however, will be diminished; since several rays will be lost in their passage through the two additional glasses.

An instrument made with glasses combined together in this manner, and inserted in a tube, is called a refracting telescope; the latter word implying, according to its signification in the Greek language, the property of seeing objects at a distance. In  
placing

Fig. 41.

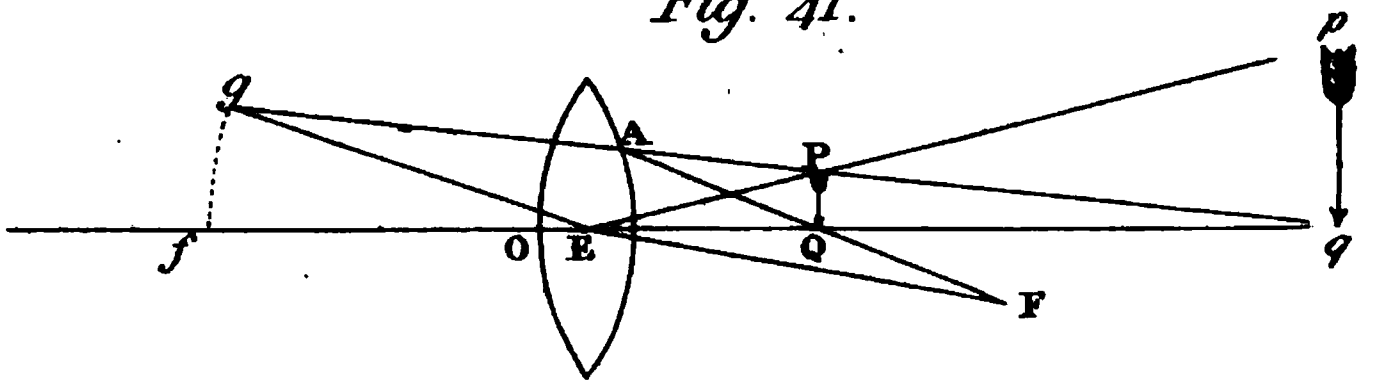


Fig. 42.

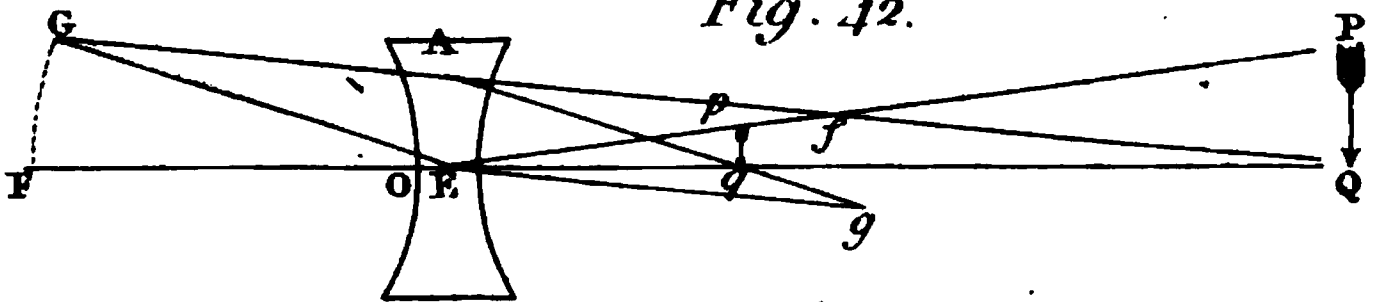


Fig. 43.

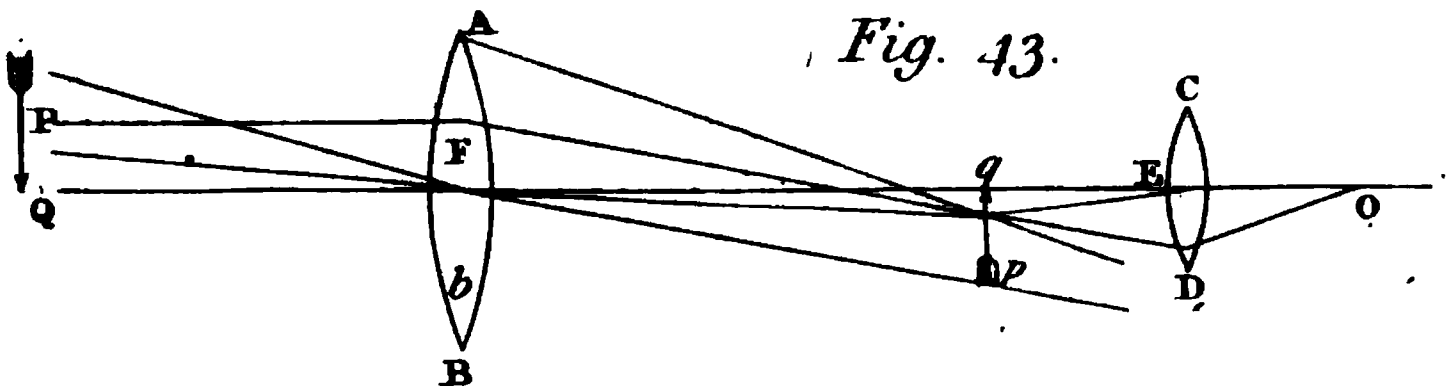


Fig. 44.

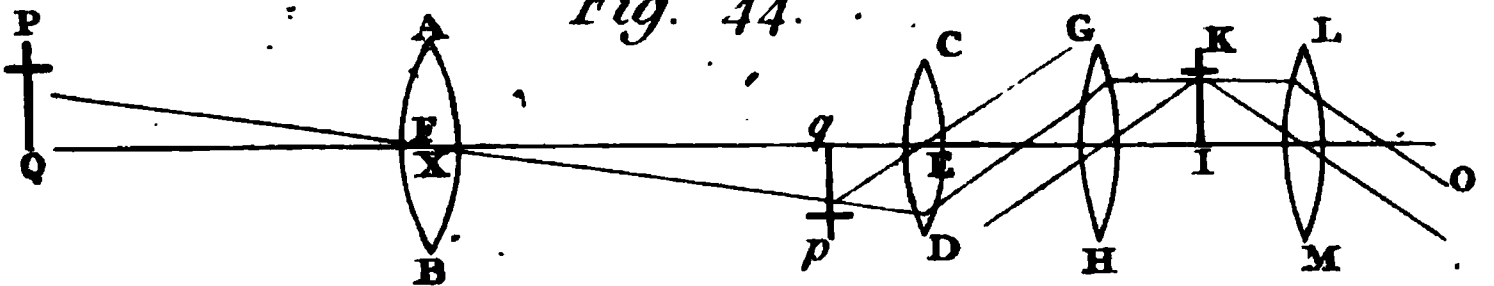
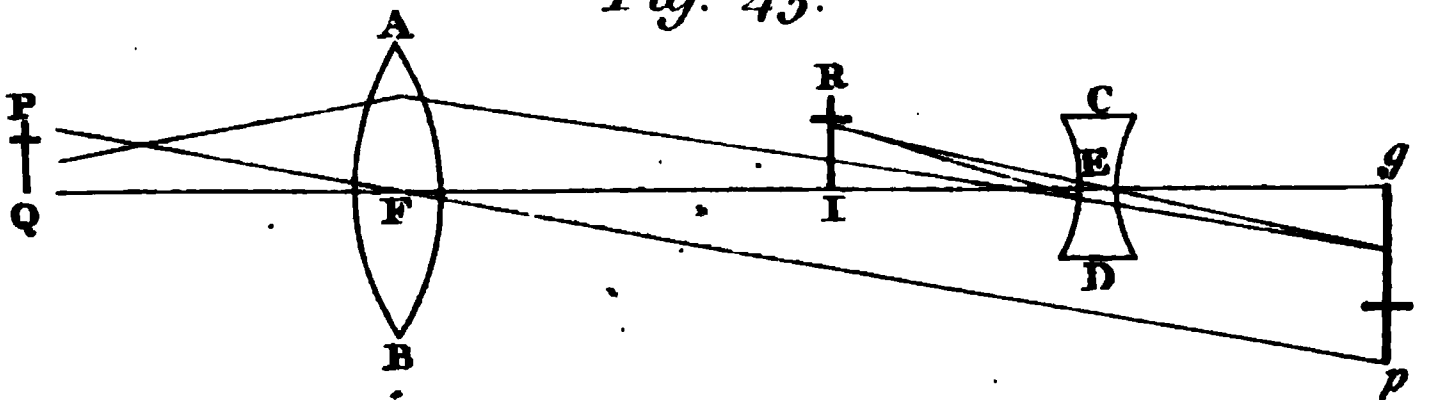


Fig. 45.





placing the glasses in this tube, care must be taken that the axes of the lenses coincide, or, as it is evident from our principles, indistinct vision only will be produced.

Instead of the two additional glasses, Galileo changed the convex eye-glass into a concave one, by which, as to the magnifying power, the same effect was produced. Thus (Fig. 45.)  $qp$  being the image of  $QP$ , by placing a double concave lens between this image and the object-glass, the rays converging to  $p$  appeared to diverge from  $R$ , and  $IR$ , the image seen by the eye at  $O$ , was made erect. In this case, the nearer the eye is placed to the glass, and the greater the pupil, the more of the object will be seen.

A microscope, or an instrument formed to inspect minute objects, is constructed exactly on the same principles. A globe of glass, or double convex lens, will, from what has been said, answer the purpose; or, a minute object, seen through two convex lenses, will be magnified in the proportion of the focal length of the object-glass to that of the eye-glass \*. In all cases, in whatever manner we combine

\* Microscopes are constructed in two different modes. The one is, by the interposition of a convex lens between the object and the eye, to render it distinct at a less distance than six inches, by which means its apparent magnitude increases as the distance is diminished; and the other is, by placing the object so with respect to a convex lens, that its focal image may be much greater than itself, and contemplating that image instead of the object. The first are called simple or

bine our glasses to discover the magnifying power, it is necessary only to compare together the angles under which the object is seen through the eye-glass,

single microscopes, and the latter compound or double. The former is constructed in this manner: suppose a small object situate very near the eye, so that the angle of its apparent magnitude may be large; then its image on the retina will also be large; but because the pencils of rays are too divergent to be collected into their foci on the retina, it will be very confused and indistinct. Then let a convex lens be interposed, so that the distance between it and the object may be equal to the focal length at which parallel rays would unite, and the rays which diverge from the object, and pass through the lens, will afterwards proceed, and consequently enter the eye, parallel; they will therefore unite, and form a distinct image on the retina, and the object will be clearly seen, though if removed to the distance of six inches, its smallness would render it invisible. The most convex lenses, having the shortest focal distance of parallel rays, must magnify the most; for they permit the object to approach nearer the eye than those do which are flatter.

A drop of water is a kind of microscope, from its convex surface; for, if a small hole is made in a plate of metal, or other thin substance, and carefully filled with a drop of water, small objects may be seen through it very distinct, and much magnified.

In the compound microscope, the image is contemplated instead of the object; it is of two kinds, the solar and the common double microscope; in the latter, the *image* is viewed through a single lens in the same manner as the *object* in a single microscope. The solar microscope is constructed by placing a convex lens opposite a hole in a darkened chamber, and placing the object at a proper distance from the lens, the pencil of light will converge to a focus on a screen, and the pencil which proceeds from the other point will converge to another focus, and the

glass, and that under which it would have been seen by the naked eye.

Instead of lenses only, for reasons hereafter to be mentioned, a combination has been formed of reflecting surfaces and lenses, and from the names of the inventors, those of the greatest use are now called the Newtonian, Gregorian \*, and Herschelian telescopes. The reflecting telescope on the Gregorian principle, which is the most common, as it is found to be the most convenient, is constructed in the following manner.

At the bottom of the great tube (Plate XII. Fig. 46.) T T T T is placed a large concave mirror D U V F, whose principal focus is at *m*, and in the middle of this mirror is a round hole P, opposite to which is placed the small mirror L, concave toward the great one, and so fixed to a strong wire M, that it may be removed further from the great mirror, or nearer to it, by means of a long screw on the inside of the tube, keeping its axis still in the same line

the intermediate points of the object will be formed into a picture, which will be as much larger than the object in proportion as the distance of the screen exceeds that of the image from the lens.

\* The difference between the Newtonian and Gregorian telescope is, that in the former the spectator looks in at the side through an aperture upon a plane mirror, by which the rays reflected from the concave mirror are reflected to the eye-glass, whereas in the latter, the reader will see that he looks through the common eye glass, which is in general more convenient, and therefore that is the telescope which is now in the most universal repute.

$Pmn$  with that of the great one. Now, since in viewing a very remote object, we can scarcely see a point of it, but what is, at least, as broad as the great mirror, we may consider the rays of each pencil, which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface  $DUVF$ . But to avoid confusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress through all their reflections and refractions to the eye  $f$  at the end of the small tube  $tt$ , which is joined to the great one.

Let us then suppose the object  $AB$  to be at such a distance, that the rays  $C$  may flow from its lower extremity  $B$ , and the rays  $E$  from its upper extremity  $A$ ; then the rays  $C$  falling parallel upon the great mirror at  $D$ , will be thence reflected converging in the direction  $DG$ , and by crossing at  $I$  in the principal focus of the mirror, they will form the upper extremity  $I$  of the inverted image  $IK$ , similar to the lower extremity  $B$  of the object  $AB$ , and passing on to the concave mirror  $L$  (whose focus is at  $n$ ) they will fall upon it at  $g$ , and be thence reflected, converging in the direction  $gN$ , because  $gm$  is longer than  $gn$ , and passing through the hole  $P$  in the large mirror, they would meet somewhere about  $r$ , and from the lower extremity  $b$  of the erect image  $ab$ , similar to the lower extremity  $B$  of the object  $AB$ . But by passing through the plano-convex glass  $R$  in their way, they form that extremity of



of the image at  $b$ . In the same manner the rays  $E$ , which come from the top of the object  $AB$ , and fall parallel upon the great mirror at  $F$ , are thence reflected, converging to its focus, where they form the lower extremity  $K$  of the inverted image  $IK$  similar to the upper extremity  $A$  of the object  $AB$ , and thence passing on to the small mirror  $L$ , and falling upon it at  $b$ , they are thence reflected in the converging state  $bo$ ; and going on through the hole  $P$  of the great mirror, they would meet somewhere about  $q$ , and form there the upper extremity  $a$  of the erect image  $ab$ , similar to the upper extremity  $A$  of the object  $AB$ ; but by passing through the convex glass  $R$  in their way, they meet and cross sooner, as at  $a$ , where that point of the erect image is formed. The like being understood of all those rays which flow from the intermediate points of the object between  $A$  and  $B$ , and enter the tube  $TT$ , all the intermediate points of the image between  $a$  and  $b$  will be formed; and the rays passing on from the image through the eye-glass  $S$ , and through a small hole  $e$  in the end of the lesser tube  $tt$ , they enter the eye  $f$ , which sees the image  $ab$  (by means of the eye-glass) under the large angle  $ced$ , and magnified in length under that angle from  $c$  to  $d$ .

In the best reflecting telescopes, the focus of the small mirror is never coincident with the focus  $m$  of the great one, where the first image  $IK$  is formed, but a little beyond it (with respect to the eye) as at  $n$ ; the consequence of which is, that the rays of the pencils will not be parallel after reflection from

from the small mirror, but converge so as to meet in points about  $q, e, r$ , where they would form a larger upright image than  $ab$ , if the glass R was not in their way, and this image might be viewed by means of a single eye-glass properly placed between the image and the eye; but then the field of view would be less, and consequently not so pleasant; for that reason the glass R is still retained to enlarge the scope or area of the field.

To find the magnifying power of this telescope, multiply the focal distance of the great mirror by the distance of the small mirror from the image next the eye, and multiply the focal distance of the small mirror by the focal distance of the eye-glass; then divide the product of the former multiplication by that of the latter, and the quotient will express the magnifying power\*.

The immensely powerful telescopes of Dr. Herschel are on a different construction. This assiduous astronomer has made several speculums, which are so perfect as to bear a magnifying power of more than six thousand times in diameter on a distant object†. The object is reflected by a mirror as in the Gregorian telescope, and the rays are intercepted by a lens at a proper distance, so that the observer has his back to the object, and looks through the lens at the mirror. The magnifying power will

\* Ferguson's Lectures, p. 235.

† See Phil. Trans. 1784.

in this case be the same as in the Newtonian telescope, but there not being a second reflector, the brightness of the object viewed in the Herschelian is greater than that in the Newtonian telescope.

There are several amusing optical deceptions, which are effected by a proper combination of plane or convex glasses. My limits will not admit of my noticing more than two of the amusing kind, namely, the magic lanthorn and the camera obscura. The former is a microscope upon the same principles as the solar microscope, and may be used with good effect for magnifying small transparent objects; but in general it is applied to the purpose of amusement, by casting the species or image of a small transparent painting on glass upon a white wall or screen, at a focal distance from the instrument.

Let a candle or lamp C (Fig. 47.) be placed in the inside of a box, so that the light may pass through the plano-convex lens N N, and strongly illuminate the object O B, which is a transparent painting on glass, inverted and moveable before N N, by means of a sliding piece in which the glass is set or fixed. This illumination is still more increased by the reflection of light from a concave mirror S S, placed at the other end of the box, that causes the light to fall upon the lens N N, as represented in the figure. Lastly a lens L L, fixed in a sliding tube, is brought to the requisite distance from the object O B, and a large erect image I M is formed upon the opposite wall.

The

The camera obscura has the same relation to the telescope, as the solar microscope has to the common double microscope, and is thus constructed:

Let *CD* (Fig. 48.) represent a darkened chamber perforated at *L*, where a convex lens is fixed, the curvity of which is such, that the focus of parallel rays falls upon the opposite wall. Then if *AB* be an object at such a distance, that the rays which proceed from any given point of its surface to the lens *L* may be esteemed parallel, an inverted picture will be formed on the opposite wall; for the pencil which proceeds from *A* will converge to *a*, and the pencil which proceeds from *B* will converge to *b*, and the intermediate points of the object will be depicted between *a* and *b*\*.

\* Nicholson's Natural Philos. vol. i. p. 347.

## CHAP. VIII.

### OF THE DIFFERENT REFRACTIBILITY OF THE RAYS OF LIGHT, AND OF CO- LOURS \*.

*Errors and Inconveniencies in optical Instruments from the Refraction of Light.—Newton, while attempting to remedy these, discovers a new Property in Light.—Phænomena and Cause of Colours.—Achromatic Telescope.—The Eye an achromatic optical Instrument.—Experiments on Colours.—Cause of the permanent Colour of opaque Bodies.*

**I**N the preceding chapters we have seen, that in finding the foci, some errors naturally arise by refraction from every surface whatever, and by reflexion from all spherical surfaces. When parallel rays are refracted by a lens (as in Plate XII. Fig. 49.) the farther the ray is from its center, the greater will be its deviation from the point F which we called the focus. This deviation MF is called the longitudinal aberration, and FN its latitudinal aberration; and as we see on a piece of paper a small circle formed by the rays of the sun

\* This subject has been partly anticipated in the 1st and 2d chapters of this book, in which it was necessary to give a superficial account of the discoveries concerning light, and of its general properties. The reader will, however, have no cause to regret a little repetition, as the subject is not very clear to a learner, and cannot be too forcibly impressed on the mind.

intercepted

intercepted by a convex lens, its magnitude depends on its radius, or the latitudinal aberration  $FN$ . This aberration depends on the aperture of the glass  $AB$ , and it does not increase in the simple proportion, but the triplicate of the semi-aperture\*. Thus, if  $PV$  and  $pV$  represent the same glass

\* Let  $Ka, Lb$ , (Plate XII. Fig. 59.) be two parallel rays very near to each other, incident on the concave refracting surface  $ACB$  at  $a, b$ , it is required to find  $m$ , the intersection of the rays after refraction. Draw  $El, EH$  the sines of incidence and refraction; and from the point  $H$  draw  $HG$  perpendicular to the radius  $Eb$ , and from  $G$  draw  $Gm$  parallel to the incident rays, and cutting the refracted ray  $bf$  in  $m$ ,  $m$  is the point required.

For  $AaE = amc + acm = amc + cEb + cbE \therefore AaE - cbE = amc + cEb = \text{Increment of the angle of refraction, and } cEb = \text{increment of the angle of incidence} \therefore \text{increment of the angle of incidence} : \text{increment of refraction} :: aEb : aEb + amb$ .

$\therefore aEb : amb :: \text{increment of incidence} : \text{increment of refraction} - \text{increment of incidence}$ .

But when the sines of angles are to each other in a given ratio, the increments of the angles vary as their tangents.

$aEb : amb :: \text{tangent of incidence} : \text{tangent of refraction} - \text{tangent of incidence}$ .

But  $HG$  is the tangent of refraction,  $HbG$  and  $OG$  is the tangent of incidence  $O b G$ ,

$\therefore aEb : amb :: OG : HO$ .

With  $m$  as center, and  $mb$  radius, describe the arc  $bd$ , then

$$aEb : amb :: \frac{ab}{Eb} : \frac{bd}{bm}.$$

Now  $ab : bd :: Eb : bH$ .

Hence  $bM : bH :: OG : HO$ , and  $Gm$  joining the points  $G$  and  $m$  is parallel to the incident rays, and consequently by drawing

Fig. 46.

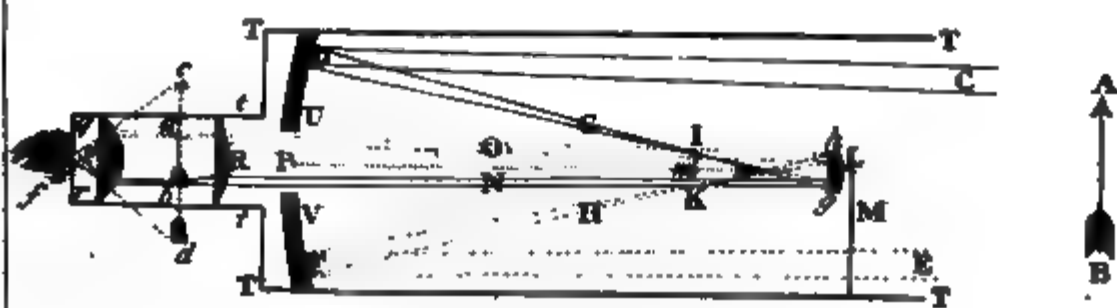


Fig. 47 Magic Lanthorn.

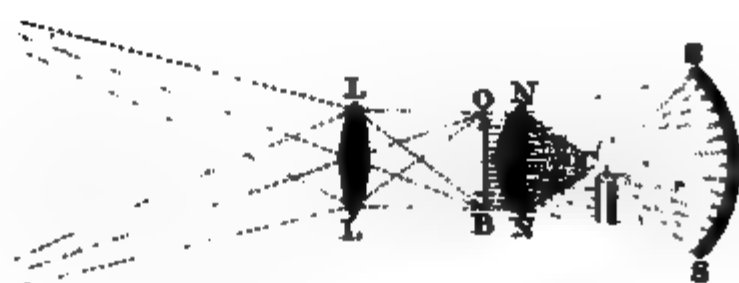
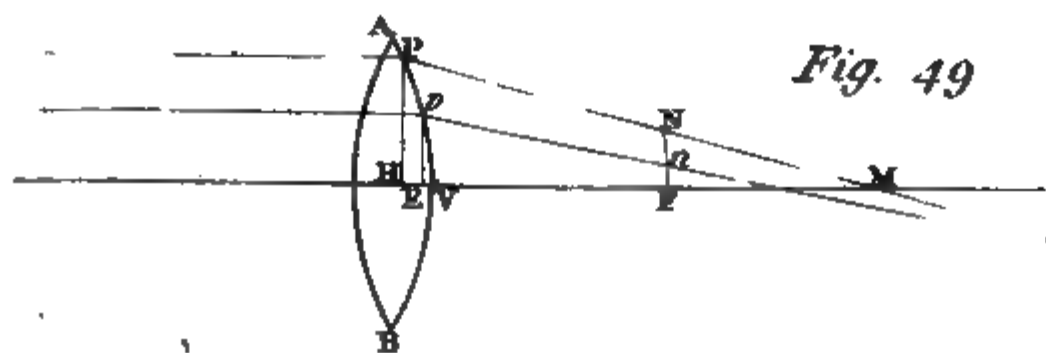


Fig. 49







glass with different apertures  $P H$ ,  $p E$ , the latitudinal aberration  $N E$  in the first case will be to that of  $n F$  in the second as the cube of  $P H$  to the cube of  $p E$ .

Philosophers,

drawing from  $G$  a parallel to the incident rays, the point of intersection of the refracted rays is determined.

Hence, since  $b H = b E \times \cos.$  of  $E b H$ , the radius being unity, the distance of the intersection from the point of incidence is found, by making as the difference of the tangents of incidence and refraction to the tangent of incidence so is radius of the surface multiplied into the  $\cos.$  of refraction, to the distance of the point of intersection from the point of incidence.

The distance  $m$  of the intersection  $m g$  from the axis  $C F$ , varies as the cube of the semi-aperture of the spherical surface.

$$\text{For } m g = D G = E G \times \sin. G E D = E G \times S. E b I$$

$$E G = H E \times \cos. H E G = H E \times S. H b E.$$

$$H E = E b \times S. H b E.$$

$$\therefore m g = E b \times S. H b E^2 \times S. E b I.$$

but  $S. H b E$  varies, as  $S. E b I$  and  $E b$  is a constant quantity.

$\therefore m g$  varies as  $S. E b I^3$ , that is as  $E I^3$ , that is as  $\text{Semi-aperture}^3$ .

If the line  $m g$  be now supposed to move parallel to itself on the axis  $C F$ , and to be made proportional in every place to the cube of the semi-aperture, a curve will be formed to which the refracted rays will be tangents, and as the adjacent rays cross each other in the points  $m$ , or the extremities of the ordinate; the light in these points will be stronger than within its area; and the curve thus formed which experiment shews to us, in various instances, is called a caustick.

All the rays incident on the surface  $b C$  will pass within the space  $m g$ , and consequently if the rays of the sun are refracted by a concave surface, and received by an opaque body perpendicular to the axis at the distance  $C g$ , a circle of light will be formed,

Philosophers, considering the errors to which they were thus exposed by the spherical form of their glasses, employed their thoughts a long time on various modes to bring the rays of light more accurately to a focus. The greatest of philosophers, Newton himself, was endeavouring to make a reflector of a parabolical form, which, if he had succeeded in his attempt, would manifestly have obviated this inconvenience, when his thoughts were turned into another channel by a discovery, which taught him that the errors arising from the spherical form of his glasses were trifling, compared with what must arise from his newly discovered property of the rays of light. Each ray, notwithstanding the exceeding minuteness of its breadth, was now found to be compounded of seven other rays, from

formed, whose density is greater at the circumference and least at its center. But though all the refracted rays will pass through the area of a circle at the distance  $Cg$ , whose diameter is  $ni$ , they will, at a greater distance from the surface, pass through a much smaller circle  $np$ , which, when it is the least, is called the circle of least diffusion, and in this circle the density of rays, and consequently the heat, is the greatest. In this circle the density of the rays will be the greatest in the center, and it decreases between the center and the circumference to a place where it is a minimum, and consequently increases again to the circumference. The investigation of this property would carry us too far into the abstruse mathematics; but what has been said sufficiently shews the nature of the diffusion of the rays of light from the figure of the surface, which is now known to occasion a much greater error, in proportion to that arising from refrangibility, than was supposed by our first philosopher.

whose

whose various combinations all the beautiful colours in nature originate.

The experiment on which this discovery is founded is thus described by Newton himself

‘ In a very dark chamber, at a round hole F (Plate XIII. Fig. 50.) about one-third of an inch broad, made in the shut of a window, I placed a glass prism A B C, whereby the beam of the sun’s light, S F, which came in at that hole, might be refracted upwards, toward the opposite wall of the chamber, and there form a coloured image of the sun, represented at P T. The axis of the prism (that is, the line passing through the middle of the prism, from one end of it to the other end, parallel to the edge of the refracting angle) was in this and the following experiments perpendicular to the incident rays. About this axis I turned the prism slowly, and saw the refracted light on the wall, or coloured image of the sun, first to descend, and then to ascend. Between the descent and ascent, when the image seemed stationary, I stopped the prism and fixed it in that posture.

‘ Then I let the refracted light fall perpendicularly upon a sheet of white paper, M N, placed at the opposite wall of the chamber, and observed the figure and dimensions of the solar image, P T, formed on the paper by that light. This image was oblong, and not oval, but terminated by two rectilinear and parallel sides and two semicircular ends. On its sides it was bounded pretty distinctly; but on its ends very confusedly and indistinctly, the light

there decaying and vanishing by degrees. At the distance of  $18\frac{1}{2}$  feet from the prism, the breadth of the image was about  $2\frac{1}{4}$  inches, but its length was about  $10\frac{1}{4}$  inches, and the length of its rectilinear sides about eight inches; and A.C.B, the refracting angle of the prism, whereby so great a length was made, was 64 degrees. With a less angle the length of the image was less, the breadth remaining the same. It is farther to be observed, that the rays went on in strait lines from the prism to the image, and therefore at their going out of the prism, had all that inclination to one another from which the length of the image proceeded. This image P T was coloured; and the more eminent colours lay in this order from the bottom at T to the top at P; red, orange, yellow, green, blue, indigo, violet, together with all their intermediate degrees, in a continual succession, perpetually varying.

Our philosopher continued his experiments, and by making the rays thus decomposed pass through a second prism, he found that they did not admit of farther decomposition, and that objects placed in the rays producing one colour always appeared to be of that colour. He then examined the ratio between the sines of incidence and refraction of these decomposed rays, and found that each of the seven primary colour-making rays, as they may be called, had certain limits within which they were confined. Thus, let the sine of incidence in glass be divided into fifty equal parts, the sine of refraction

refraction into air of the least and most refrangible rays will contain respectively 77 and 78 such parts. The lines of refraction of all the degrees of red will have the intermediate degrees of magnitude, from 77 to  $77\frac{1}{8}$ , orange from  $77\frac{1}{8}$  to  $77\frac{1}{4}$ , yellow from  $77\frac{1}{4}$  to  $77\frac{1}{2}$ , green from  $77\frac{1}{2}$  to  $77\frac{3}{4}$ , blue from  $77\frac{3}{4}$  to  $77\frac{7}{8}$ , indigo from  $77\frac{7}{8}$  to  $77\frac{7}{8}$ , and violet from  $77\frac{7}{8}$  to 78.

According to the properties of bodies in reflecting or absorbing these rays, the colours which we see in them are formed. If every ray falling upon an object was reflected to our eyes, it would appear white; if every ray was absorbed it would appear black; between these two appearances innumerable species of colours may be formed by reflection or transmission of the various combinations of the colour making rays\*. If the rays also of light were

\* The original or component rays of light are separable from each other, not only by refraction, or by varying the angle of incidence on a reflecting surface, but are likewise at like incidences more or less reflectible, according to the thickness or distance between the two surfaces of the medium on which they fall. They are also liable to be turned out of their direct course by approaching within a certain distance from a body, by which means a separation ensues, the rays being more or less deflected as they differ in colour. Of these circumstances it will be proper to give some account.

If a convex glass or lens, or a portion of a sphere, is laid upon another plane glass, it is evident that it will rest or touch at one particular point only; and, therefore, that at all other places between the adjacent surfaces will be interposed a thin plate of air, the thickness of which will increase in a certain

were not thus compounded, every object would appear of the same colour, and an irksome uniformity would prevail over the face of nature.

We have seen that when rays of light were refracted by any surface, the focus after refraction depended on the ratio between the sines of incidence and refraction, and that this focus was not a mathematical point. The reader will naturally infer, that the aberration must be considerably increased, when for each order of colour-making rays a different ratio between these sines must be assumed. Common observers, without understanding the cause, may be made sensible of this by noticing

ratio, according to the distance from the point of contact. Light incident upon such a plate of air is disposed to be transmitted or reflected according to its thickness; thus, at the center of contact, the light is transmitted, and a black circular spot appears; this spot is environed by a circle, the colours of which, reckoning from the internal part, are blue, white, yellow, red; then follows another circular series, viz. violet, blue, green, yellow, red; then purple, blue, green, yellow, red; green, red; greenish blue, red; greenish blue, pale red; greenish blue, reddish white.

These are the colours which appear by reflection. By the transmitted light the following series are seen. At the center, white, then yellowish red, black, violet, blue, white, yellow, red, &c.; so that the transmitted light at any thickness, instead of white, appears of the compounded colour which it ought to have after the subtraction of some of the constituent colours by reflection; after which series, the colours become too faint and diluted to be discerned. It is curious to observe, that the glasses will not come into contact without a considerable degree of pressure. *Nicholson's Philosophy*, vol. i. p. 282.

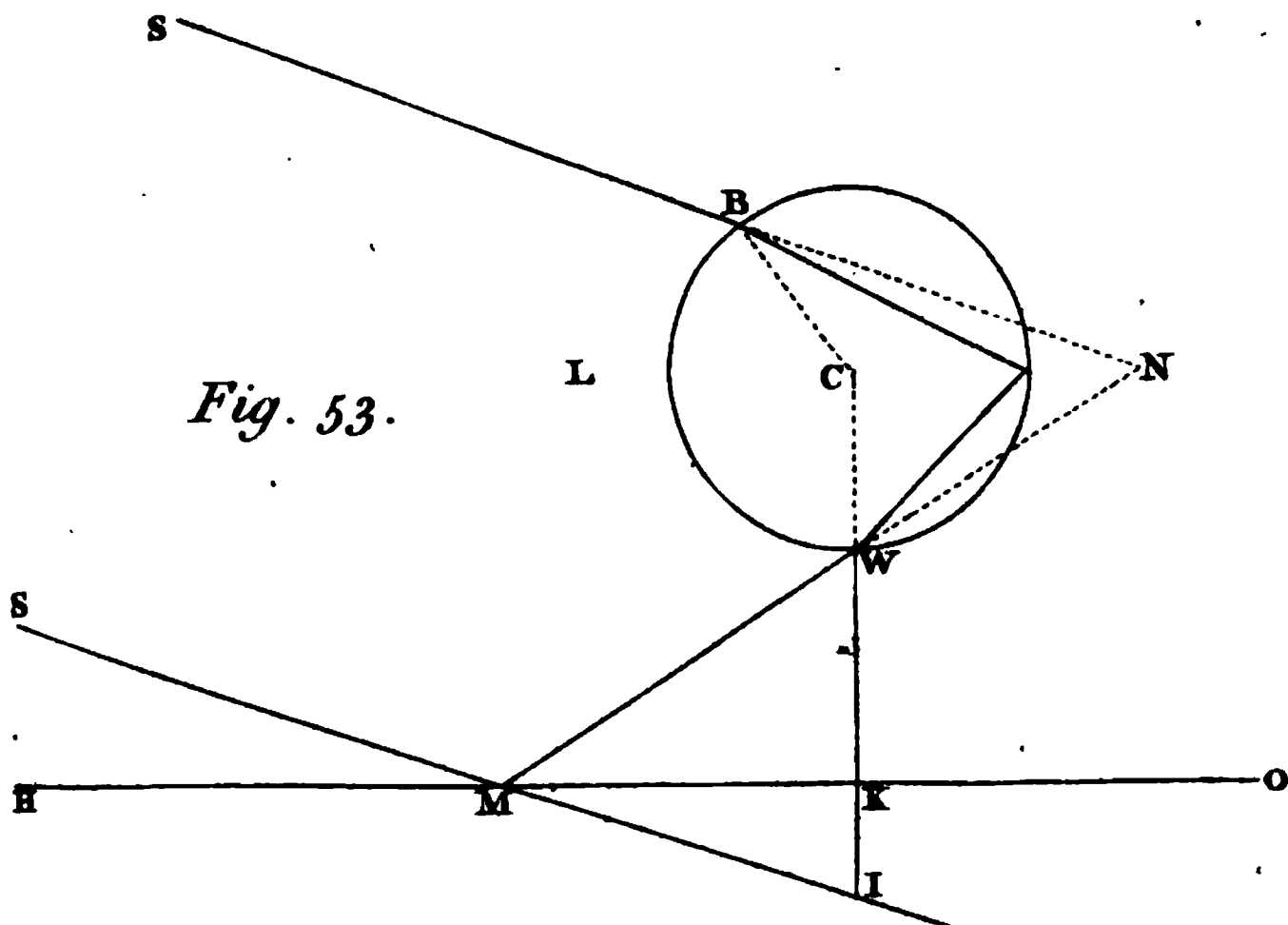
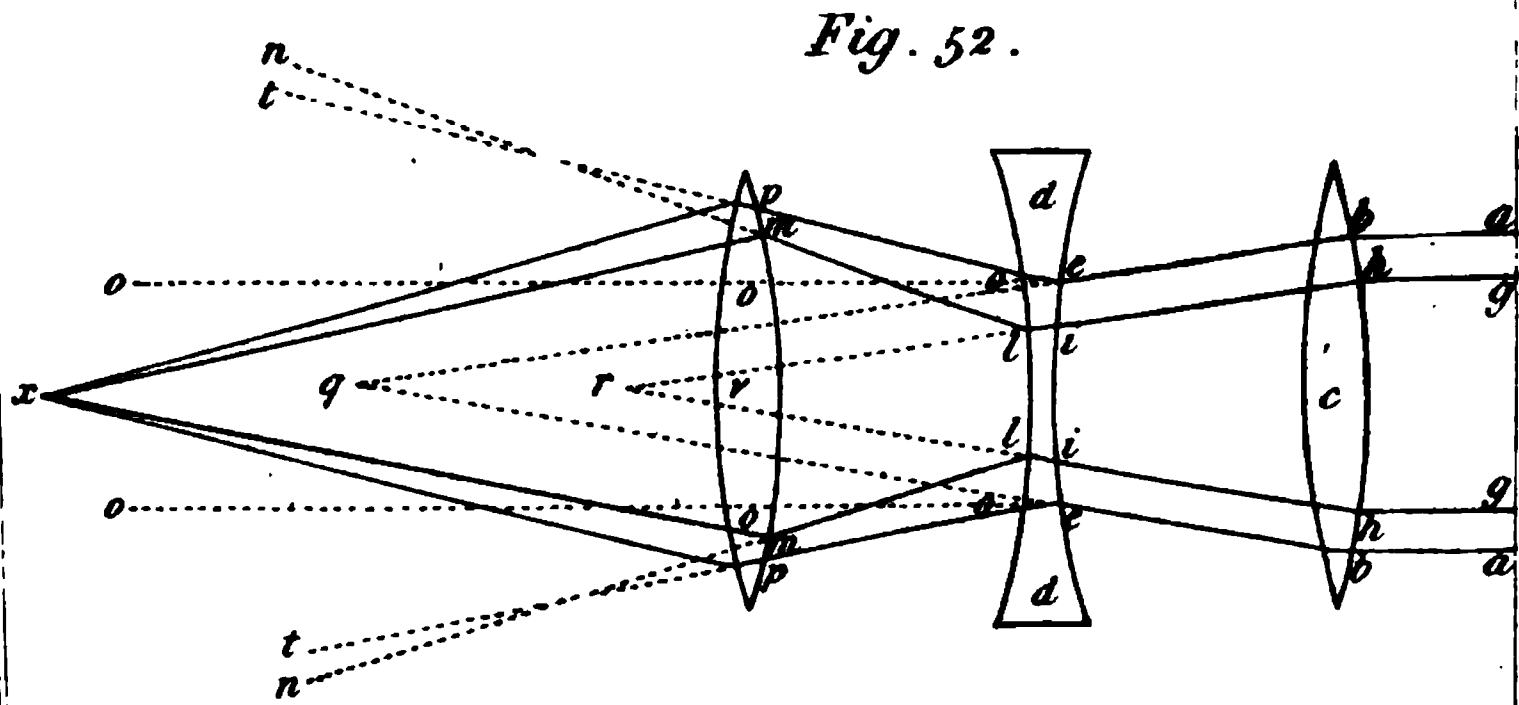
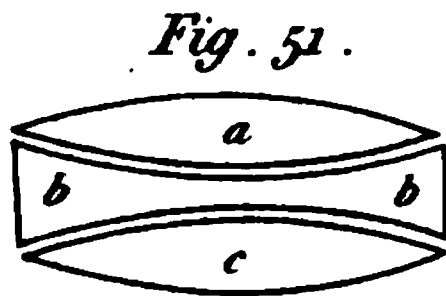
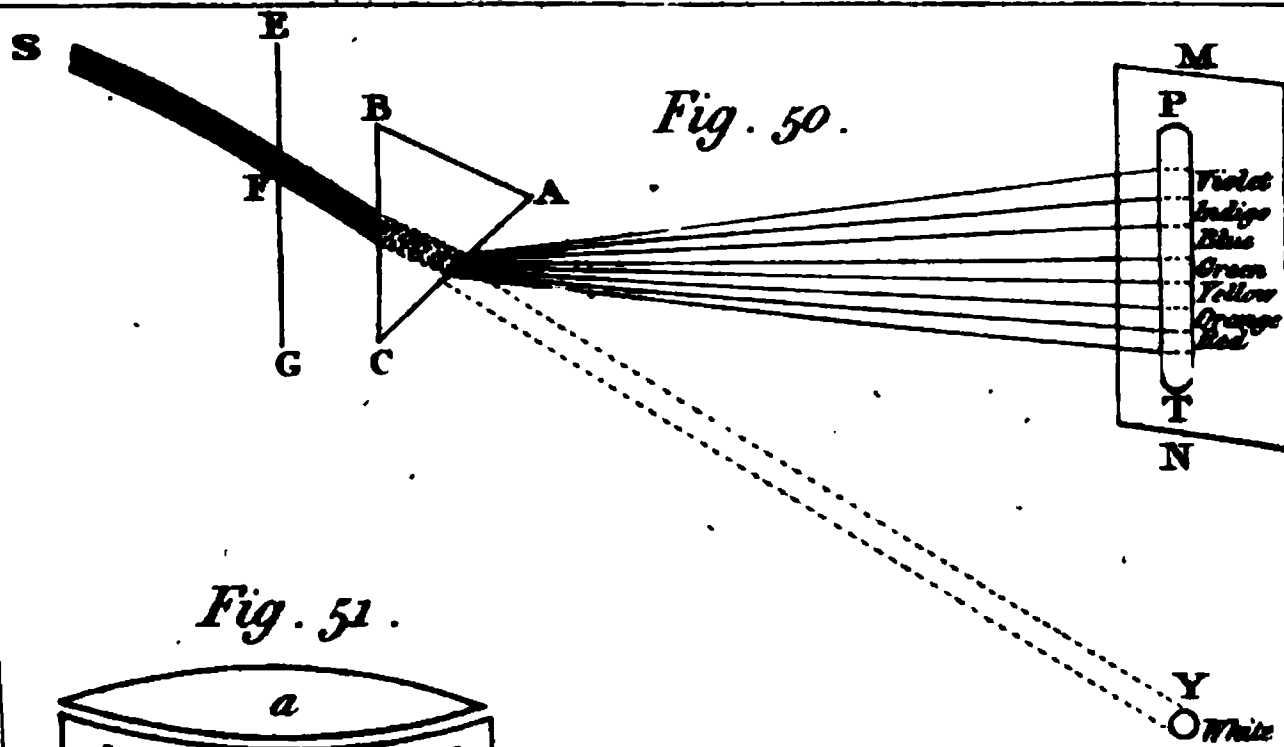
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the colours of objects seen through a telescope; and from the difficulty of the subject it might seem impossible that any remedy should be applied to the inconvenience. Yet who shall set bounds to the sagacity of man? Mathematicians could point out certain combinations of forms and refrangible powers by which the rays might come colourless, as the white making rays are commonly called, to the eye; and a celebrated optician of our own times, Mr. Dollond, has had the merit of realizing, in great measure, their theories. By making a compound lens of three different substances of different refrangible powers, the rays of light, which were dispersed too much by one convex lens, are brought nearer to an union with each other, and the telescopes made with an object glass of this kind are now commonly used, and well known by the name of achromatic telescopes; the word achromatic being used by that pedantry which infects most of our philosophers, who love to give a Greek word, unintelligible to the greater part of their readers, instead of the equally significant term in our own language, colourless.

The object-glasses of Mr. Dollond's telescopes are composed of three distinct lenses, two convex and one concave; of which the concave one is placed in the middle, as is represented in Fig. 51. where *a* and *c* show the two convex lenses, and *b b* the concave one, which is by the British artists placed in the middle. The two convex ones are made of London crown glass, and the middle one of white flint glass; and they are all ground to spheres

of different radii, according to the refractive powers of the different kinds of glass, and the intended focal distance of the object-glass of the telescope. According to Boscovich, the focal distance of the parallel rays for the concave lens is one-half, and for the convex glass one-third of the combined focus. When put together, they refract the rays in the following manner. Let  $ab$ ,  $ab$  (Fig. 52.) be two red rays of the sun's light falling parallel on the first convex lens  $c$ . Supposing there was no other lens present but that one, they would then be converged into the lines  $be$ ,  $be$ , and at last meet in the focus  $q$ . Let the lines  $gb$ ,  $gb$ , represent two violet rays falling on the surface of the lens: These are also refracted, and will meet in a focus; but as they have a greater degree of refrangibility than the red rays, they must of consequence converge more by the same power of refraction in the glass, and meet sooner in a focus, suppose at  $r$ .—Let now the concave lens  $d$  be placed in such a manner as to intercept all the rays before they come to their focus. If this lens was made of the same materials, and ground to the same radius with the convex one, it would have the same power to cause the rays to diverge that the former had to make them converge. In this case, the red rays would become parallel, and move on in the line  $o'o$ ,  $oo$ : but the concave lens, being made of flint glass, and upon a shorter radius, has a greater refractive power, and therefore they diverge a little after they come out of it; and if no third lens was interposed, they would proceed diverging







verging in the lines  $o p t$ ,  $o p t$ ; but, by the interposition of the third lens  $o.v o$ , they are again made to converge, and meet in a focus somewhat more distant than the former, as at  $x$ . By the concave lens the violent rays are also refracted, and made to diverge: but having a greater degree of refrangibility, the same power of refraction makes them diverge somewhat more than the red ones; and thus, if no third lens was interposed, they would proceed in such lines as  $l m n$ ,  $l m n$ . Now as the differently coloured rays fall upon the third lens with different degrees of divergence, it is plain, that the same power of refraction in that lens will operate upon them in such a manner as to bring them all together to a focus very nearly at the same point. The red rays, it is true, require the greatest power of refraction to bring them to a focus; but they fall upon the lens with the least degree of divergence. The violet rays, though they require the least power of refraction, yet have the greatest degree of divergence; and thus all meet together at the point  $x$ , or very nearly so \*.

The more we investigate the works of nature, the greater reason have we to admire the wisdom of its author, and that wonderful adaptation of our organs, in the minutest particulars, to the general laws which pervade the universe. The subject before us affords a striking instance to corroborate this remark. We have hitherto supposed the eye to be a lens capable only of enlarging and contracting,

\* Encyclop. Brit. vol. xiii. p. 354.

and consequently, from the description now given of the rays of light, it must be incapable of obviating the confusion which must arise from their different degrees of refrangibility. But here the use of that wonderful structure of parts, and the different fluids in the eye, is clearly seen. The eye is, in fact, a complex lens. Each fluid has its proper degree of refrangible power. The shape of the lenses is altered at will, according to the distance of the object; and the three substances having the proper powers of refrangibility, the effects of an achromatic glass are without difficulty performed by the eye, whose mechanical structure and judicious arrangement of substances it is in vain for the art of man to imitate.

From what has been stated, the principal phenomena of colours may, without much difficulty, be explained.

If all the different-coloured rays which the prism affords are re-united by means of a concave mirror, the produce will be *white*; yet these same rays, which, taken together, form white, give, after the point of their re-union, that is, beyond the point where they cross each other, the same colours as those which departed from the prism, but in a reversed order, by the crossing of the rays; the reason of which is clear; for the ray being white before it was divided by the prism, must necessarily become so by the re-union of its parts, which the difference of refrangibility had separated, and this re-union cannot in any manner tend to alter or destroy the  
nature

nature of the colours; it follows then that they must appear again beyond the point of crossing.

In the same manner, if we mix a certain proportion of red colour with orange, yellow, green, blue, indigo, and violet, a colour will be produced which resembles that which is made by mixing a little black with white, and which would be entirely white if some of the rays were not lost or absorbed by the grossness of the colouring matter.

A colour nearly approaching to white is also formed by colouring a piece of round pasteboard with the different prismatic colours, and causing it to be turned round so rapidly that no particular colour can be perceived.

If to a single ray of the sun divided by the prism, which will then form an oblong-coloured spectrum, a thick glass deeply coloured with one of the primitive colours is applied, for example red, the light which passes through will appear red only, and will form a round image.

If two thick glasses, the one red and the other green, are placed one upon another, they will produce a perfect opacity, though each of them, taken separately, is transparent, because the one permits the red rays only to pass through it, and the other only green ones, therefore when these two glasses are united, neither of those kind of rays can reach the eye, because the first permits only red rays to pass, whereas the second receives only green ones, which are the only rays it can transmit.

If the rays of the sun are made to fall very obliquely

liquely upon the interior surface of a prism, the violet-coloured rays will be reflected, and the red, &c. will be transmitted; if the obliquity of incidence is augmented, the blue will be also reflected, and the other transmitted; the reason of which is, that the rays which have the most refrangibility are also those which are the easiest reflected\*.

In whatever manner we examine the colour of a single prismatic ray, we shall always find, that neither refraction, reflection, nor any other means, can make it forego its natural hue; but if we examine the artificial colouring of bodies by a microscope, it will appear a rude heap of colours, unequally mixed. If we mix a blue and yellow to make a common green, it will appear moderately beautiful to the naked eye; but when we regard it with microscopic attention, it seems a confused mass of yellow and blue parts, each particle reflecting but one separate colour.

To determine the cause of the permanent colours of opake bodies, a series of experiments was instituted by Mr. Delaval, as noticed in the historical part of this book. He prepared a great variety of coloured fluids, which he put in phial bottles of a square form. The backs of these phials he coated over with an opake substance, leaving the front of the phial uncovered, and the whole of the neck. On exposing them to the incident light, he found, that from the parts of the phials which were covered at the back no light whatever was reflected, but it was

\* Briffon, *Traité Elem. de Physique*, tom. ii. page 361.

perfectly

perfectly black, while the light transmitted through the uncoated parts of the phials was of different colours. The same fluids, spread thinly on a white ground, exhibited their proper colours; the light indeed being in this case reflected from the white ground, and transmitted through a coloured medium. It is almost unnecessary to add, that when spread upon a black ground they afforded no colour.

The same experiments were repeated with glass tinged of various colours, and the result was perfectly the same. When these glasses are of such a thinness, and are tinged so dilutely that light is transmitted through them, they appear vividly coloured; when in larger masses, and the tinging matter more densely diffused through them, they are black; when the transmitted light, in the transparent plates of these glasses, was intercepted by covering the further surface, they appeared black.

From these different phenomena Mr. Delaval clearly deduces these remarks—1st, That the colouring particles do not reflect any light. 2dly, That a medium, such as Sir Isaac Newton has described, is diffused over the anterior and further surfaces of the plates, whereby objects are reflected equally and regularly as in a mirror.

When a lighted candle is placed near one of these coloured plates, the flame is reflected by the medium diffused over the anterior surface; the image thus reflected resembles the flame in size and colour, for it is scarcely sensibly diminished, and is not at all tinged with colours; if the plate is not very  
massy,

massy, or too deeply tinged, there appears a secondary image of the flame, reflected from the further surface of the glass, and as the light, thus reflected, passes back through the coloured glass, it is vividly tinged.

The secondary image is less than that which is reflected from the anterior surface. This diminution is occasioned by the loss of that part of the light which is absorbed in passing through the coloured glass.

The next object of this ingenious philosopher was to obtain the colouring particles pure and unmixed with other media. To this end he reduced several transparent coloured liquors to a solid consistence by evaporation, and in this state the colouring particles reflected no light, but were entirely black.

To determine the principle on which opaque bodies appear coloured, it is therefore only necessary, in the first place, to recollect, that all the coloured liquors appeared such only by transmitted light; and 2dly, that these liquors, spread thinly upon a white ground, exhibited their respective colours; he therefore concludes, that all coloured bodies, which are not transparent, consist of a substratum of some white substance, which is thinly covered with the colouring particles.

On extracting carefully the colouring matter from the leaves, wood, and other parts of vegetables, he found that the basis was a substance perfectly white. He also extracted the colouring matter from different



rent animal substances; from flesh, feathers, &c. whence the same conclusion was directly proved.

Flesh consists of fibrous vessels, containing blood, and is perfectly white when divested of the blood by ablution; and the florid red colour of the flesh proceeds from the light which is reflected from the white fibrous substance, through the red transparent covering formed by the blood.

The result was the same from an examination of the mineral kingdom.

Some portions of light are reflected from every surface of a body, or from every different medium into which it enters. Thus, transparent bodies reduced to powder appear white, which is no other than a copious reflection of the light from all the surfaces of the minute parts, and from the air which is interposed between these particles.

The general appearance of a strong infusion of cochineal is black; but when agitated, its surface is covered with a red froth. The reason is, that the light is reflected from the globules of air inclosed in each of the bubbles which constitute the froth, and is transmitted through the films of red liquor which cover them. Several vitreous substances in like manner appear black in a solid mass, but when powdered, of a different colour. The action of these powders on the rays of light is the effect of the discontinuance of their parts, and the air being admitted into the interstices, the light is transmitted through the thin transparent particles of the glass, which give it that tinge which the powder exhibits.

If oil, instead of air, intercedes the interstices of powdered substances, in proportion as it approaches to the density of the substances themselves, and as it exceeds air in this respect, it renders the colour proportionably darker. “ Thus when indigo, and other transparent paints, are united with oil, the air is expelled from their interstices, and the oil which is admitted in its stead, from the nearness of its density to that of the powder, reflects no sensible light, so that the mass, which consists of such uniformly dense media, is black.” “ When smooth surfaces of dark-coloured marble or slate, or any other polished substance, are scratched, the air enters into the interstices which are opened by this operation, and according to the excess of its rarity over that of the masses which it intercedes, it reflects a whiter or lighter-coloured hue. By polishing the surface also, the air is removed from them, and the dark hue is restored.”

From these experiments he concludes, “ that vegetable, animal, and mineral coloured matter is transparent; that it does not reflect colours, but only exhibits them by transmission; that opake coloured bodies consist of transparent matter covering opake white particles, and transmitting the light which is reflected from them.”

With respect to the semi-pellucid substances, such as the solution of *lignum nephriticum*, &c. which appear of one colour by incident and another by transmitted light, he says, “ they consist of pellucid media, through which white or colourless opake particles

particles are diffused. These white particles, he adds, are disposed at such distances from each other, that some of the incident rays of light are capable of passing through the intervals which intercede them, and thus are transmitted through the semi-pellucid mass. Some sorts of rays penetrate through the masses, whilst other sorts, which differ from them in refrangibility, are refracted by the white or colourless particles. Thus, when pellucid colourless glass is melted with arsenic, the arsenic is thereby divided into minute opaque particles, which are equally diffused through the glass. If only a small quantity of arsenic is used in this compound, the white particles are thinly disseminated in it. When glass of this composition is held between the window and the eye, it exhibits a yellow or orange tinge; when viewed by incident light it is blue. The yellow or orange arises from the less refrangible rays, from the mixture of which that colour results. The more refrangible are reflected back by the white particles.

## CHAP. IX.

## OF THE RAINBOW, AND OTHER REMARKABLE PHENOMENA OF LIGHT.

*Of the primary and secondary Rainbow.—Why the Phenomenon assumes the Form of an Arch.—At what Angles the different Colours are apparent.—Lunar Rainbow.—Marine Bow.—Coloured Bows seen on the Ground.—Halo or Corona.—Curious Phenomena seen on the Top of the Cordilleras.—Similar Appearance in Scotland.—Parhelion, or Mock Suns.—Singular Lunar Phenomenon.—Blue Colour of the Atmosphere.—Red Colour of the Morning and Evening Clouds.—Colour of the Sea.*

SINCE the rays of light are found to be decomposed by refracting surfaces, we can no longer be surprised at the changes produced in any object by the intervention of another. The vivid colours, which gild the rising or the setting sun, must necessarily differ from those, which adorn its noon day splendor. There must be the greatest variety which the liveliest fancy can imagine. The clouds will assume the most fantastic forms, or will lower with the darkest hues, according to the different rays which are reflected to our eyes, or the quantity absorbed by the vapours in the air. The ignorant multitude will necessarily be alarmed by the sights in the heavens, by the appearance at one time of three, at another of five suns, of circles

cles of various magnitudes round the sun or moon, and thence conceive that some fatal change must take place in the physical or the moral world, some fall of empires or tremendous earthquakes, while the optician contemplates them merely as the natural and beautiful effects produced by clouds or vapour in various masses upon the rays of light.

One of the most beautiful and common of these appearances deserves particular investigation, as, when this subject is well understood, there will be little difficulty in accounting for others of a similar nature, dependant on the different refrangibility of the rays of light. Frequently, when our backs are turned to the sun, and there is a shower either around us or at some distance before us, a species of bow is seen in the air, adorned with the seven primary colours. The appearance of this bow, in poetical language called the iris, and in common language the rainbow, was an inexplicable mystery to the antients; and, though now well understood, continues to be the subject of admiration to the peasant and the philosopher.

We are indebted to Sir Isaac Newton for the explanation of this appearance, and by various easy experiments we may convince any man that his theory is founded on truth. If a glass globe is suspended in the strong light of the sun, it will be found to reflect the different prismatic colours exactly in proportion to the position in which it is placed; in other words, agreeably to the angle which it forms with the spectator's eye and the incidence of

the rays of light. The fact is, that innumerable pencils of light fall upon the surface of the globe, and each of these is separated as by a prism. To make this matter still clearer, let us suppose the circle B O W (Plate XIV. Fig. 53.) to represent the globe, or a drop of rain, for each drop may be considered as a small globe of water. The red rays, it is well known, are least refrangible; they will therefore be refracted, agreeably to their angle of incidence, to a certain point O in the most distant part of the globe; the yellow, the green, the blue, and the purple rays will each be refracted to another point. A part of the light, as refracted, will be transmitted, but a part will also be reflected; the red rays at the point O, and the others at certain other points, agreeably to their angle of refraction.

It is very evident, that if the spectator's eye is placed in the direction of M W, or the course of the red making rays, he will only distinguish the red colour; if in another station, he will see only by the yellow rays; in another, by the blue, &c.: but as in a shower of rain there are drops at all heights and all distances, all those that are in a certain position with respect to the spectator will reflect the red rays, all those in the next station the orange, those in the next the green, &c.

To avoid confusion let us for the present imagine only three drops of rain, and three degrees of colours in the section of a bow (Fig. 54.) It is evident that the angle C D E is less than the angle B D E,

B D E, and that the angle A D E is the greatest of the three. This largest angle then is formed by the red rays, the middle one consists of the green, and the smallest is the purple. All the drops of rain, therefore, that happen to be in a certain position to the eye of the spectator, will reflect the red rays, and form a band or semicircle of red; those again in a certain position will present a band of green, &c. If he alters his station, the spectator will still see a bow, though not the same bow as before; and if there are many spectators they will each see a different bow, though it appears to be the same.

There are sometimes seen two bows, one formed as has been described, the other appearing externally to embrace the primary bow, and which is sometimes called a secondary or false bow, because it is fainter than the other; and what is most remarkable is, that in the false bow the order of the colours appears always reversed.

In the true, or primary bow, we have seen that the rays of light arrive at the spectator's eye after two refractions and one reflection; in the secondary bow, on the other hand, the rays are sent to our eyes after two refractions and two reflections, and the order of the colours is reversed, because in this latter case the light enters at the inferior part of the drop, and is transmitted through the superior. Thus (Fig. 55.) the ray of light which enters at B is refracted to O, whence it is reflected to P, and again reflected to W, where, suffering ano-

ther refraction, it is sent to the eye of the spectator. The colours of this outer bow are fainter than those of the other, because, the drop being transparent, a part of the light is transmitted, and consequently lost, at each reflection.

The phenomenon assumes a semicircular appearance, because it is only at certain angles that the refracted rays are visible to our eyes. The least refrangible, or red rays, make an angle of forty-two degrees two minutes, and the most refrangible or violet rays an angle of forty degrees seventeen minutes. Now if a line is drawn horizontally from the spectator's eye, it is evident that angles formed with this line, of a certain dimension in every direction, will produce a circle, as will be evident by only attaching a cord of a given length to a certain point, round which it may turn as round its axis, and in every point will describe an angle with the horizontal line of a certain and determinate extent.

Let  $HO$ , for instance (Fig. 53.) represent the horizon,  $BW$  a drop of rain at any altitude,  $SB$  a line drawn from the sun to the drop, which will be parallel to a line  $SM$  drawn from the eye of the spectator to the sun. The course of part of the decomposed ray  $SB$  may be first by refraction from  $B$  to  $O$ , then by reflection from  $O$  to  $W$ , lastly by refraction from  $W$  to  $M$ . Now all drops, which are in such a situation that the incident and emergent rays  $SB$ ,  $MW$  produced through them make the same angle,  $SNM$  will be the means of exciting in the specta-

tors



tors the same idea of colour \*. Let  $MW$  turn upon  $HO$  as an axis till  $W$  meets the horizon on both sides, and the point  $W$  will describe the arc of a circle, and all the drops placed in its circumference will have the property we have mentioned, of transmitting to the eye a particular colour. When the plane  $H M W O$  is perpendicular to the horizon, the

\* Half the angle between the incident and emergent rays is equal to the difference between  $m$  times the angle of refraction and the angle of incidence;  $m$  being equal to the number of reflections added to unity.  $BCL = CBN + CNB$ , and also  $BCK = COB + CBO = 2. CBO$ .

$$\therefore CBN + CNB = 2. CBO.$$

$$\therefore CNB = 2. CBO - CBN.$$

$CNB$  is half the angle between the incident and emergent rays, and  $2 = m$ , there being in this case only one reflection; and by pursuing the enquiry in the same manner when the number of reflections is increased, it will appear that  $CNB$  always equals  $m. CBO - CBN$ .

This angle  $CNB$ , if the angle of incidence increases from nothing, first increases and then decreases, therefore  $m CBO - CBN$  will in some place be a maximum; that is, where  $m$  times the fluxion of  $CBO$ , is equal to the fluxion of  $CBN$ .

Let  $CBO = A$  and  $CBN = B$ .

$$\therefore \dot{A} : \dot{B} :: 1 : m$$

and radius being equal to unity

$$\dot{A} : \dot{B} :: \frac{\dot{S} A}{\text{col. } A} : \frac{\dot{S} B}{\text{col. } B} :: \frac{S A}{\text{col. } A} : \frac{S B}{\text{col. } B}$$

$$\text{but tang. } A : \text{tang. } B :: \frac{S. A}{\text{col. } A} : \frac{S. B}{\text{col. } B}$$

$$\therefore \text{Tang. } A : \text{tang. } B :: 1 : m$$

S 3

Hence

the line  $MW$  is directed to the vertex of the bow, and  $WK$  is its altitude.

This

Hence the problem is reduced to a question to find two angles whose sines and tangents shall be to each other in a given ratio.

Let  $x = \text{cof. of } A$ .

$y = \text{cof. of } B$ .

$$\therefore \sqrt{1-x^2} = \text{fine } A, \text{ and } \frac{\sqrt{1-x^2}}{x} = T A.$$

$$\sqrt{1-y^2} = \text{fine } B, \frac{\sqrt{1-y^2}}{y} = T B$$

$$1-x^2 : 1-y^2 :: R^2 : I^2$$

$$\frac{1-x^2}{x^2} : \frac{1-y^2}{y^2} :: 1 : m^2.$$

$$\therefore x^2 : y^2 :: m^2 R^2 : I^2$$

$$\therefore x^2 = \frac{m^2 R^2 y^2}{I^2}$$

$$1-x^2 = \frac{I^2 - m^2 R^2 y^2}{I^2}$$

$$\therefore \frac{I^2 - m^2 R^2 y^2}{I^2} : 1-y^2 :: R^2 : I^2$$

$$I^2 - m^2 R^2 y^2 = R^2 - R^2 y^2$$

$$I^2 - R^2 = m^2 R^2 y^2 - R^2 y^2$$

$$\therefore 1 : y :: R \times \sqrt{m^2 - 1} : \sqrt{I^2 - R^2}$$

Hence the cosine of one angle being found, its sine is given, and from thence the sine of the other angle, since they are in a given ratio to each other.

Thus, according to the nature of the bow, whether primary, secondary, &c. the greatest angle between the incident and emergent rays is found; but in this case the rays entering just above or below the point where the incident ray makes the greatest angle between the incident and emergent rays must, after emerging from the drop, proceed nearly parallel to each other, and consequently a number of rays of one colour will

Fall

This altitude depends on two things, the angle between the incident and emergent rays, and the height of the sun above the horizon; for since  $SM$  is parallel to  $SN$ , the angle  $SNM$  is equal to  $NMI$ , but  $SMH$ , the altitude of the sun, is equal to  $KMI$ , therefore the altitude of the bow  $WMK$ , which is equal to the difference between  $WMI$  and  $KMI$ , is equal to the difference between the angles made by the incident and emergent rays and the altitude of the sun.

The angle between the incident and emergent rays is different for the different colours, as was already intimated; for the red or least refrangible rays it is equal to  $42^{\circ} 2'$ ; for the violet, or most refrangible, it is equal to  $40^{\circ} 17'$ ; consequently when the sun is more than  $42^{\circ} 2'$  above the horizon, the red colour cannot be seen; when it is above  $40^{\circ} 17'$ , the violet colour cannot be seen.

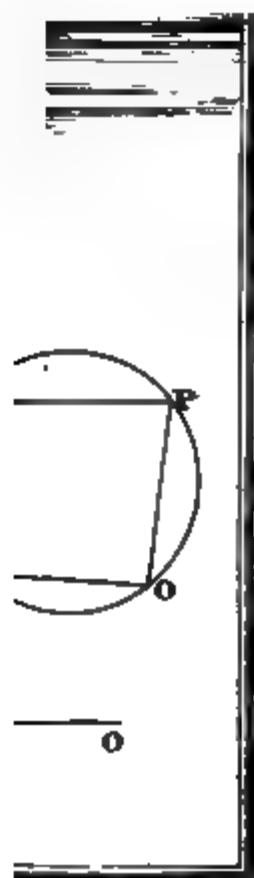
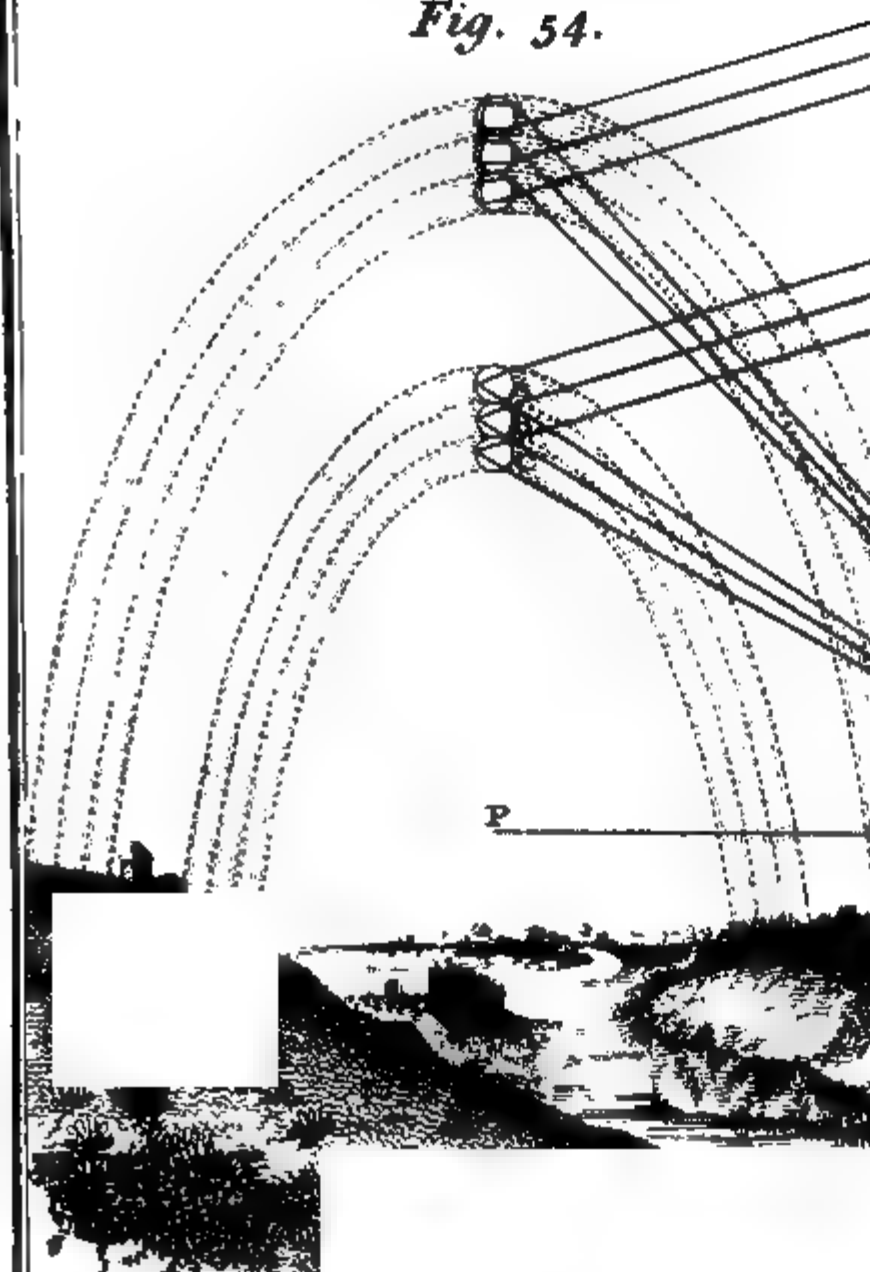
The secondary bow, as I have said, is made in a similar manner, but the sun's rays suffer, in this case, two reflections within the drop. The ray  $SB$  is decomposed at  $B$  and one part is refracted to  $O$ , thence reflected to  $P$ , and from  $P$  reflected to  $W$ , where it is refracted to  $M$ . The angle between the incident and emergent rays  $SNM$  is equal as before to  $NMI$ , and  $NMK$ , the height of the bow, is equal to the difference be-

fall upon the eye, diverging from the point where the angle between the incident and emergent rays is the greatest, and produce the appearance of that colour at the thus determined height in the skies.

tween the angle made by the incident and emergent rays and the height of the sun. In this case the angle  $S N M$ , for the red rays, is equal to  $50^{\circ} 7'$ , and for the violet rays it is equal to  $54^{\circ} 7'$ ; consequently the upper part of the secondary bow will be seen only when the sun is above  $54^{\circ} 7'$  above the horizon, and the lower part of the bow will be seen only when the sun is  $50^{\circ} 7'$  above the horizon.

In the same manner bows might be formed without end by a greater number of reflections within the drops; but as the secondary is so much fainter than the primary, that all the colours in it are seldom seen, for the same reason a bow made with three reflections would be fainter still, and in general altogether imperceptible. Since the rays of light, by various reflections and refractions, are thus capable of forming, by means of drops of rain, the bows which we so frequently see in the heavens, it is evident that there will be not only solar and lunar bows, but that many striking appearances of colours will be made by drops upon the ground; or air on the agitated surface of the water. Thus a lunar bow will be formed by rays from the moon affected by drops of rain, but as its light is very faint in comparison with that of the sun, such a bow will very seldom be seen, and the colours of it, when seen, will be faint and dim. I was once a spectator of a lunar bow, in the course of a pedestrian expedition by moonlight in the autumnal season. The night was uncommonly light, though showery, and the colours

Fig. 54.





lours much more vivid than I could have conceived; indeed I have seen rainbows by day not more conspicuous. There were not, however, so many colours distinguishable as in the solar bow.

The marine or sea bow is a phenomenon sometimes observed in a much agitated sea; when the wind, sweeping part of the tops of the waves, carries them aloft; so that the sun's rays, falling upon them, are refracted, &c. as in a common shower, and paint the colours of the bow.

Rohault mentions coloured *bows* on the grass, formed by the refraction of the sun's rays in the morning dew.

Dr. Langwith, indeed, once saw a bow lying on the ground, the colours of which were almost as lively as those of the common rainbow. It was extended several hundred yards. It was not round; but oblong, being, as he conceived, the portion of an hyperbola. The colours took up less space, and were much more lively in those parts of the bow which were near him than in those which were at a distance.

The drops of rain descend in a globular form, and thence we can easily account for the effects produced by them on the rays of light; but in different states of the air, instead of drops of rain vapour falls to the earth in different forms of fleet, snow, and hail. In the two latter states there cannot be a refraction of the rays of light, but in the former state, when a drop is partly in a congealed and partly in a fluid form, the rays of light will be differently affected,

fects, both from the form of the drop and its various refracting powers. Hence we may expect a variety of curious appearances in the heavens, and to these drops, in different states, we may attribute the formation of halos, parhelia, and many other phenomena, detailed in the philosophical transactions, or in the histories of every country.

The halo or corona, is a luminous circle surrounding the sun, the moon, a planet, or a fixed star. It is sometimes quite white, and sometimes coloured like the rainbow. Those which have been observed round the moon or stars are but of a very small diameter; those round the sun are of different magnitudes, and sometimes immensely great. When coloured, the colours are fainter than those of the rainbow, and appear in a different order, according to their size. In those which Sir Isaac Newton observed in 1692, the order of the colours, from the inside next the sun, was in the innermost, blue, white, red; in the middle, purple, blue, green, yellow, pale red; in the outermost, pale blue and pale red. Hugen observed one red next the sun, and pale blue at the extremity. Mr. Weidler has given an account of one yellow on the inside and white on the outside. In France one was observed, in which the order of the colours was, white, red, blue, green, and a bright red on the outside\*.

Artificial coronas may be made in cold weather, by placing a lighted candle in the midst of a cloud

\* Priestley's Hist. of Opt. p. 597.



of steam; or if a glass window is breathed upon, and the flame of a candle placed at some distance from the window, while the operator is also at the distance of some feet from another part of the window, the flame will be surrounded with a coloured halo.

I was once witness to a very pleasing phenomenon. The full moon was partly obscured behind the skirt of a very thin white cloud, which, as it grew thinner towards the edge, had the full effect of a prism in separating the rays of light, and exhibited the colours of the rainbow in their proper gradations.

When M. Bouguer was on the top of mount Pichinea, in the Cordilleras, he and some gentlemen who accompanied him, observed a most remarkable phenomenon. When the sun was just rising behind them, and a white cloud was about thirty paces from them, each of them observed his own shadow (and no other) projected upon it. All the parts of the shadow were distinct, and the head was adorned with a kind of glory, consisting of three or four concentric crowns, of a very lively colour, each exhibiting all the varieties of the primary rainbow, and having the circle red on the outside.

Similar to this appearance was one which occurred to Dr. M'Fait, in Scotland. This gentleman observed a rainbow round his shadow in a mist, when he was situated on an eminence above it. In this situation the whole country appeared to be immersed in a vast deluge, and nothing but the  
7 tops

tops of hills appeared here and there above the flood; at another time he observed a double range of colours round his shadow \*.

The parhelia, or mock suns, are the most splendid phenomena of this kind. We find these appearances frequently adverted to by the ancients, who generally considered them as formidable omens. Four mock suns were seen ~~an once~~ by Scheiner at Rome, and by Muschenbroek at Utrecht; and seven were observed by Hevelius at Sedan, in 1661 †.

The parhelia generally appear about the size of the true sun, not quite so bright, though they are said sometimes to rival their parent luminary in splendor. When there are a number of them they are not equal to each other in brightness. Externally they are tinged with colours like the rainbow. They are not always round, and have sometimes a long fiery tail opposite the sun, but paler towards the extremity. Dr. Halley observed one with tails extending both ways. Mr. Weidler saw a parhelion with one tail pointing up and another downwards, a little crooked; the limb which was farthest from the sun being of a purple colour, the other tinged with the colours of the rainbow ‡.

Coronas generally accompany parhelia, some coloured and others white. There is also in general a very large white circle, parallel to the horizon,

\* Priestley's Opt. p. 600.

† Priestley's Hist. Opt. p. 613.

‡ Ib. p. 614.

which

which passes through all the parhelia; and, if it was entire, would go through the center of the sun; sometimes there are arches of smaller circles concentric to this, and touching the coloured circles which surround the sun; they are also tinged with colours, and contain other parhelia.

One of the most remarkable appearances of this kind was that which was observed at Rome by Scheiner, as intimated above, and this may serve as a sufficient instance of the parhelion.

This celebrated phenomenon is represented in Pl. XV. Fig. 56. in which A is the place of the observer, B his zenith, C the true sun, A B a plane passing through the observer's eye, the true sun, and the zenith. About the sun C, there appeared two concentric rings, not compleat, but diversified with colours. The lesser of them, D E F, was fuller, and more perfect; and though it was open from D to F, yet those ends were perpetually endeavouring to unite, and sometimes they did so. The outer of these rings was much fainter, so as scarcely to be discernible. It had, however, a variety of colours, but was very inconstant. The third circle, K L M N, was very large, and all over white, passing through the middle of the sun, and every where parallel to the horizon. At first this circle was entire; but towards the end of the phenomenon it was weak and ragged, so as hardly to be perceived from M towards N.

In the intersection of this circle, and the outward iris G K I, there broke out two parhelia, or mock  
suns,

fun, N and K, not quite perfect, K being rather weak, but N shone brighter and stronger. The brightness of the middle of them was something like that of the sun, but towards the edges they were tinged with colours like those of the rainbow, and they were uneven and ragged. The parhelion N was a little wavering, and sent out a spiked tail N P, of a colour somewhat fiery, the length of which was continually changing.

The parhelia at L and M, in the horizontal ring, were not so bright as the former, but were rounder, and white, like the circle in which they were placed. The parhelion N disappeared before K; and while M grew fainter, K grew brighter, and vanished the last of all.

It is to be observed farther, that the order of the colours in the circles D E F, G K N was the same as in the common halo's, namely red next the sun, and the diameter of the inner circle was also about 45 degrees; which is the usual size of a halo.

Parhelia have been seen for one, two, three, and four hours together; and in North America they are said to continue some days, and to be visible from sun rise to sun set. When they disappear, it sometimes rains, or snow falls in the form of oblong spiculæ\*.

Mr. Wales says, that at Churchill, in Hudson's Bay, the rising of the sun is always preceded by two long streams of red light. These rise as the sun rises; and as they grow longer begin to bend

\* Priestley's Hist. Opt. p. 614 to 617.

towards each other, till they meet directly over the sun, forming there a kind of parhelion or mock sun.

These two streams of light, he says, seem to have their source in two other parhelia, which rise with the true sun; and in the winter season, when the sun never rises above the haze or fog, which he says is constantly found near the horizon, all these accompany him the whole day, and set with him in the same manner as they rise. Once or twice he saw a fourth parhelion under the true sun, but this, he adds, is not common.\*

The cause of these is apparently the reflection of the sun's light and image from the thick and frozen clouds in the northern atmosphere, accompanied also with some degree of refraction. To enter upon a mathematical analysis of these phenomena would be only tedious, and very foreign to our purpose. From what has been said upon this subject it is evident, that all the phenomena of colours depend upon two properties of light, the refrangibility and reflexibility of its rays.

The blue colour of the atmosphere has been beautifully accounted for by Mr. Delaval, in the experiments already noticed. The atmosphere he considers as a semi-pellucid medium, which abounds in volatile and evaporable particles, disengaged from natural bodies by several operations, as fermentation, effervescence, putrefaction, &c. These particles

\* Priestley's Hist. Opt. p. 617.

differ greatly in density, &c. from the air, and, as they reflect a white light, may be considered as so many white particles diffused through the pellucid colourless air. In this respect the atmosphere is similar to the semi-pellucid medium, which is formed by a mixture of arsenic with glass. In both these substances, whilst the white particles are rarely disseminated through the transparent medium, the less refrangible rays are transmitted through the intervals which intercede the particles\*, but the more refrangible rays are intercepted and reflected by the particles, and the mixture of those rays produces a blue colour.

In air, as well as in the solid semi-pellucid media, when the white particles are more densely arranged, the intervals which intercede them are diminished, and in this state of the atmosphere a great proportion of all the rays are reflected, so as to produce the effect of perfect whiteness, or at least an approach towards it. Thus, when the part of the atmosphere, which is near the surface of the earth, is occupied by gross vapours, this mixture of air with aqueous or other particles is white: such is the common appearance of fogs. When such vapours are elevated high in the atmosphere, and form

\* On this account, distant mountains covered with snow (which it is well known reflect all the rays of the sun) appear, when the air is thick, and the sun nearly opposite them, of a warmer colour than they otherwise would, and more approaching to yellow or orange.

clouds, they reflect the white light of the sun, and appear white, whenever its incident rays fall on them entire and undivided; and as the reflecting particles are not equally diffused through every part of the pellucid air, of which the atmosphere principally consists, it frequently happens that large tracts of air are only furnished with such a portion as qualify them to reflect a blue colour, while others are so densely stored as to form clouds.

Of the red and vivid colour of the morning and evening clouds Mr. Melville has suggested a cause upon similar principles, which we must at least allow is ingenious and probable. He supposes, as well as Mr. Delaval, that a separation of the rays is made in passing through the horizontal atmosphere, and that the clouds reflect and transmit the sun's light, as any half transparent colourless body would do; for as the atmosphere reflects a greater quantity of blue and violet rays than of the rest, the sun's light transmitted through it inclines towards yellow, orange, or red, especially when it passes through a long tract of air; and in this manner the sun's horizontal light is tinged with a deep orange, and even red, and the colour becomes still deeper after sun-set; hence he concludes, that the clouds, according to their different altitudes, may assume all the variety of colours at sun rising and setting, by barely reflecting the sun's incident light as they receive it.

The green colour of the sea may also be accounted for in the same manner. Sir Isaac Newton, and others, have supposed that this effect was

produced by the reflective power of the water; but that this is not the case is manifest; for when sea water is admitted into a reservoir, which does not exceed a few inches in depth, it appears pellucid and colourless.

Dr. Halley, in the diving-bell \*, observed, that when he was sunk many fathoms deep into the sea, the upper part of his hand, on which the sun shone directly through the water, was red, and the lower part a blueish green. On these phenomena Mr. Delaval observes, that the sea water abounds with heterogeneous particles, many of which approach so near in density to the water itself, that their reflective power must be very weak, though, as they are not quite of the same density, they still must have some degree of reflective power. Although these, therefore, may be invisible when separately viewed, yet when the forces of a great number of such minute bodies are united, their action on the rays of light becomes perceptible, some rays being reflected by them, whilst others are transmitted through their intervals, according to the quantity of reflective matter which the rays arrive at in the internal parts of the water.

The opacity of the sea, caused by the numerous reflections from its internal parts, is so considerable, that it is not near so transparent as other water; the reflective particles, therefore, which are dispersed through the mass of sea water, have consequently a

\* Newton's Opt. l. 1. Part 2d.



greater reflective power than those which are dispersed through the atmosphere. Instead, therefore, of reflecting a delicate blue, such as that of the sky, the sea water, by acting upon a greater portion of the more refrangible rays, exhibits a green colour, which we know to be a middle colour produced by the mixture of blue rays with some of the less refrangible, as the yellow or orange.

With respect to the phenomena remarked by Dr. Halley, it is easy to conceive that the light, when stripped of all the more refrangible rays, should produce a rose colour, such as that he observed on the upper part of his hand; on the contrary, that which illuminated the lower part of his hand consisted partly of rays reflected from the ground, and partly of those which were reflected from the internal parts of the sea water, which, we have seen, are chiefly blue and violet; and the mixture of these produced the greenish tinge which the Doctor remarked \*, and which common experience shews is the predominant colour of the ocean.

\* Delaval on the causes of colours in opake bodies, v. ii. Manch. Mem.

## CHAP. X.

## OF THE INFLECTION OF LIGHT.

*Retrospect of the Doctrine of Reflection.—Nature of Inflection.—Newton's Experiments.—Analogy between this Property and Refraction.—Curious Effects from this Property.*

THE direction of the rays of light is changed, as we have seen, in their approach to certain bodies, by reflection and refraction, and consequently we must admit that there is some power in these bodies by which such effects are universally produced. If reflection was produced simply by the impinging of particles of light on hard or elastic bodies, or if they were in themselves elastic, the same effects would follow as in the impulse of other elastic bodies; but the angle of incidence could not be equal to the angle of reflection, unless the particles of light were perfectly elastic, or the bodies on which they impinged were perfectly elastic. Now we know that the bodies on which these particles impinge are not perfectly elastic, and also that if the particles of light were perfectly elastic, the diffusion of light from the reflecting bodies would be very different from its present appearance; for as no body can be perfectly polished, the particles of light which are so inconceivably small would be reflected

reflected back by the inequalities on the surface in every direction; consequently we are led to this conclusion, that the reflecting bodies have a power which acts at some little distance from their surfaces.

If this reasoning is allowed to be just, it necessarily follows, that if a ray of light, instead of impinging on a body, should pass so near to it as to be within the sphere of that power which the body possesses, it must necessarily suffer a change in its direction. Actual experiments confirm the truth of this position, and to the change in the direction of a particle of light, owing to its nearness to a body, we give the name of inflection.

From one of these experiments, made by Sir Isaac Newton, the whole of this subject will be easily understood. At the distance of two or three feet from the window of a darkened room, in which was a hole three-fourths of an inch broad, to admit the light, he placed a black sheet of pasteboard, having in the middle a hole about a quarter of an inch square, and behind the hole the blade of a sharp knife, to intercept a small part of the light which would otherwise have passed through the hole. The planes of the pasteboard and blade were parallel to each other, and when the pasteboard was removed at such a distance from the window, as that all the light coming into the room must pass through the hole in the pasteboard, he received what came through this hole on a piece of paper two or three feet beyond the knife, and perceived

two streams of faint light shooting out both ways from the beam of light into the shadow. As the brightness of the direct rays obscured the fainter light, by making a hole in his paper he let them pass through, and had thus an opportunity of attending closely to the two streams, which were nearly equal in length, breadth, and quantity of light. That part which was nearest to the sun's direct light was pretty strong for the space of about a quarter of an inch, decreasing gradually till it became imperceptible, and at the edge of the knife it subtended an angle of about twelve or at most fourteen degrees.

Another knife was then placed opposite to the former, and he observed, that when the distance of their edges was about the four hundredth part of an inch, the stream divided in the middle, and left a shadow between the two parts, which was so dark, that all light passing between the knives seemed to be bent aside to one knife or the other; as the knives were brought nearer to each other, this shadow grew broader, till upon the contact of the knives the whole light disappeared.

Pursuing his observations upon this appearance, he perceived fringes, as they may be termed, of different coloured light, three made on one side by the edge of one knife, and three on the other side by the edge of the other, and thence concluded, that as in refraction the rays of light are differently acted upon, so are they at a distance from bodies by inflection; and by many other experiments of the same





*Fig. 59.*



same kind he supported his position, which is confirmed by all subsequent experiments.

We may naturally conclude, that from this property of inflection some curious changes will be produced in the appearances of external objects. If we take a piece of wire of a less diameter than the pupil of the eye and place it between the eye and a distant object, the latter will appear magnified (Fig. 57.) Let A be a church steeple, B the eye, C the wire. The rays by which the steeple would have been otherwise seen are intercepted by the wire, and it is now seen by inflected rays, which make a greater angle than the direct rays, and consequently the steeple will be magnified.

In nearly shutting the eyes, and looking at a candle, there appear rays of light extending from it in various directions, like comets' tails; for the light, in passing through the eye-lashes, is inflected, and consequently many separate beams will be formed, diverging from the luminous object. The power of bodies to inflect the rays of light passing near to them will produce different effects, according to the nature of the rays acted upon; consequently a separation will take place in the differently refrangible rays, and those fringes, which were taken notice of by Sir Isaac Newton, will appear in other objects which are seen by the means of inflected rays. From considering thus the action of bodies upon light, we come to this general conclusion, for which we are indebted to our great philosopher,

that light, as well as all other matter, is acted upon at a distance; and that reflection, refraction, and inflection, are owing to certain general laws in the particles of matter, which are equally necessary for the preservation of the beautiful harmony in the objects nearest to us, as to produce by their joint action that great law by which the greater bodies in their system are retained in their respective orbits.



B O O K   I V .  
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C H A P .   I .

HISTORY OF DISCOVERIES RELATIVE TO  
ELECTRICITY.

*Origin of the Name.—How far Electricity was known to the Ancients.—Mr. Boyle.—Otto Guericke.—Dr. Wall.—Mr. Hawksbee.—Mr. Grey's Discoveries.—M. Du Fay's.—Subsequent Discoveries of Mr. Grey.—Improvements of German Philosophers.—Leyden Phial.—Electrical Battery.—Spirits fired by Electricity conducted through the River Thames.—Two Species of Electricity discovered.—Dr. Franklin's great Discoveries.*

**T**HE attractive power which amber, and other electric bodies, acquire by friction, was long known to philosophers ; and it is unnecessary to remark, that this branch of science derives its name from *ελεκτρον* (electron) the Greek word for amber. The other electric properties were slowly discovered. Mr. Boyle was the first who had a glimpse of the electric light ; as he remarked, after rubbing some diamonds in order to give them the power of attraction, that they afforded light in the dark.

Otto

Otto Guericke, burgomaster of Magdeburg, made an electric globe of sulphur, and by whirling it about in a wooden frame, and rubbing it at the same time with his hand, he performed various electrical experiments. He added to the stock of knowledge the discovery, that a body once attracted by an excited electric was repelled by it, and not attracted again till it had touched some other body. Thus he was able to keep a feather suspended in the air over his globe of sulphur ; but he observed, if he drove it near a linen thread, or the flame of a candle, it instantly recovered its propensity (if I may use the expression) for approaching the globe again. The hissing noise, and the gleam of light which his globe afforded, both attracted his notice.

These circumstances were, however, afterwards accurately remarked by Dr. Wall, who, by rubbing amber upon a woollen substance in the dark, found also that light was produced in considerable quantities, accompanied with a crackling noise ; and what is still more extraordinary, he adds, “ this light and crackling seems, in some degree, to represent thunder and lightning.”

Mr. Hawksbee first observed the great electric power of glass. He constructed a wooden machine, which enabled him conveniently to put a glass globe in motion. He confirmed all the experiments of Dr. Wall. He observed, that the light emitted by the friction of electric bodies, besides the crackling noise, was accompanied by an acute  
sense

sense of feeling when applied to his hand. He says, that all the powers of electricity were improved by warmth, and diminished by moisture.

Hitherto the distinction between those bodies which are capable of being excited to electricity and those which are only capable of receiving it from the others, appears scarcely to have been suspected. About the year 1729, this great discovery was made by Mr. Grey, a pensioner of the Charter-House. After some fruitless attempts to make metals attractive by heating, rubbing, and hammering, he conceived a suspicion, that as a glass tube, when rubbed in the dark, communicated its light to various bodies, it might possibly at the same time communicate its power of attraction to them. In order to put this to the trial, he provided himself with a tube three feet five inches long, and near an inch and one fifth in diameter; the ends of the tube were stopped by cork; and he found that when the tube was excited, a down feather was attracted as powerfully by the cork as by the tube itself. To convince himself more completely, he procured a small ivory ball, which he fixed at first to a stick of fir four inches long, which was thrust into the cork, and found that it attracted and repelled the feather even with more vigour than the cork itself. He afterwards fixed the ball upon long sticks, and upon pieces of brass and iron wire, with the same success; and lastly, attached it to a long piece of packthread, and hung it from a high balcony, in which state he found,

found, that by rubbing the tube the ball was constantly enabled to attract light bodies in the court below.

His next attempt was to prove, whether this power could be conveyed horizontally as well as perpendicularly; with this view he fixed a cord to a nail which was in one of the beams of the ceiling, and making a loop at that end which hung down, he inserted his packthread, with the ball which was at the end of it, through the loop of the cord, and retired with the tube to the other end of the room; but in this state he found that his ball had totally lost the power of attraction. Upon mentioning his disappointed efforts to a friend, it was suggested, that the cord which he had used to support his packthread might be so coarse as to intercept the electric powers, and they accordingly attempted to remedy this evil by employing a silk string, which was much stronger in proportion than a hempen cord. With this apparatus the experiment succeeded far beyond their expectations. Encouraged by this success, and attributing it wholly to the fineness of the silk, they proceeded to support the packthread, to which the ball was attached, by very fine brass and iron wire, but, to their utter astonishment, found the effect exactly the same as when they used the hempen cord; the electrical virtue utterly passed away; while on the other hand, when the packthread was supported by a silken cord, they were able to convey the electric virtue seven hundred and sixty-five feet.

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It was evident, therefore, that these effects depended upon some peculiar quality in the silk, which disabled it from conducting away the electrical power, as the hempen cord and the wire had done. This, probably, immediately led to the discovery of other non-conducting bodies, and *hair, rosin, glass, &c.* were presently made use of to insulate the bodies which were electrified. The next obvious improvement was to electrify separate bodies, by placing them upon non-conductors; and in this manner Mr. Grey and his friend Mr. Wheeler electrified a large map, a table cloth, &c. &c. In the latter end of the same summer, Mr. Grey found that he could electrify a rod as well as a packthread, without inserting any part into his excited tube, and that it only required to be placed nearly in contact with the apparatus.

Mr. Grey proceeded to try the effects of electricity upon animal bodies. He suspended a boy on hair lines in a horizontal position, and bringing the excited tube near his feet, he found that leaf brass was attracted very vigorously by the head of the boy. He found also, that he could communicate electricity to fluid bodies, by insulating them upon a cake of rosin; and observed, that when an excited tube was held over a cup of water, the water was presently attracted, in a conical form, towards the tube; that the electric matter passed from the tube to the water with a slight flash and a crackling noise; and that the fluid subsided with a tremulous and waving motion.

After

After this period the spirit of philosophy in this branch was no longer confined to England. M. Du Fay, intendant of the French king's gardens, added to the stock of discoveries. He found that all bodies, except metallic, soft, and fluid ones, might be made electric by first heating them, and then rubbing them on any sort of cloth. He also excepts those substances which grow soft by heat, as gums, or which dissolve in water, as glue. In pursuing Mr. Grey's experiments with a packthread, &c. he perceived that they succeeded better by wetting the line. To prove the effects of this wonderful agent on the animal body, he suspended himself by silk cords, as Mr. Grey had suspended the boy, and in this situation he observed, that as soon as he was electrified, if another person approached him, and brought his hand, or a metal rod, within an inch of his body, there immediately issued from it one or more prickling shoots, attended with a snapping noise; and he adds, that this experiment occasioned a similar sensation in the person who placed his hand near him: in the dark he observed, that these snappings were occasioned by so many sparks of fire.

Mr. Grey, on resuming his experiments, immediately concluded from that of M. Du Fay, in which a piece of metal drew sparks from the person electrified, and suspended on silk lines, that if the person and the metal changed places the effect would be the same. He accordingly suspended a piece of metal by silk threads near his excited tube,  
and

and found he drew sparks from it at pleasure. This was the origin of metallic conductors. Mr. Grey suspected that the electric fire might be of the same nature with thunder and lightning.

To the philosophers of Germany we are indebted for most of the improvements in the electrical apparatus. They revived the use of the globe, which had been invented by Mr. Hawksbee, which was afterwards superseded by a cylinder, and to which they imparted a circular motion by means of wheels, and used a woollen rubber instead of the hand. By the great force also of their machines, they were able to fire some of the most inflammable substances, such as highly rectified spirits, by the electric spark.

But the most surprizing discovery was that which immediately followed these attempts, in the years 1745-6; I mean the method of accumulating the electric power by the Leyden phial. M. Von Kleist, dean of the cathedral of Camnin, was the first who found that a nail or brass wire, confined in an apothecary's phial, and exposed to the electrifying glass or prime conductor, had a power of collecting the electric virtue so as to produce the most remarkable effects; he soon found that a small quantity of fluid added to it increased the power; and successive electricians found, that fluid matter, or any conducting body confined in a glass vessel, had this power of accumulating and condensing (if I may use the expression) the electric virtue. The shock which an electrician is enabled to give by means of

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the Leyden phial is well known; and this was soon followed by another improvement, that of forming what is called the electric battery, by increasing the number of phials, by which means the force is proportionably increased. By these means the electric shock was tried upon the brute creation, and proved fatal to many of the smaller animals, which appeared as if killed by lightning. By these means also the electric matter was conveyed to great distances; by the French philosophers, for near three miles; and by Dr. Watson, and some other members of the Royal Society, it was conveyed, by a wire, over the river Thames, and back again through the river, and spirits were kindled by the electric fire which had passed through the river. In another experiment by the same gentleman, it was found that the electric matter made a circuit of about four miles almost instantaneously.

The next discovery respects the nature, or rather the origin, of the electric matter. Dr. Watson was first induced to suspect that the glass tubes and globes did not contain the electric power in themselves, by observing, that upon rubbing the glass tube while he was standing on cakes of wax (in order to prevent, as he expected, any of the electric matter from discharging itself through his body on the floor) the power was so much lessened that no snapping could be observed upon another person's touching any part of his body; but that if a person not electrified held his hand near the tube while it was rubbed, the snapping was  
very



very sensible. The event was the same when the globe was whirled in similar circumstances; for if the man who turned the wheel, and who, together with the machine, was suspended upon silk, touched the floor with one foot, the fire appeared upon the conductor; but if he kept himself free from any communication with the floor, no fire was produced. From these and other decisive experiments Dr. Watson concludes, that these globes and tubes are no more than the first movers or determiners of the electric power.

M. Du Fay had made a distinction of two different species of electricity, one of which he called the *vitreous*, and the other the *resinous* electricity; and soon after the discovery of the Leyden phial, it was found, that by coating the outside of the phial with a conducting substance, which communicated by a wire with the person who discharged the phial, the shock was immensely increased; and indeed it appeared, that the phial could not be charged unless some conducting substance was in contact with the outside. Dr. Franklin, however, was the first who explained these phenomena. He shewed that the surplus of electricity, which was received by one of the coated surfaces of the phial, was actually taken from the other; and that one was possessed of less than its natural share of the electric matter, while the other had a superabundance. These two different states of bodies, with respect to their portion of electricity, he distinguished by the

terms *plus* or positive, and *minus* or negative; and it was inferred from the appearances, that bodies which exhibited what M. Du Fay called the resinous electricity, were in the state of *minus*, that is, in the state of attracting the electric matter from other bodies, while those which were possessed of the vitreous electricity were bodies electrified *plus*, or in a state capable of imparting electricity to other bodies. By this discovery Dr. Franklin was enabled to increase the electric power almost at pleasure, namely, by connecting the outside of one phial with the inside of another, in such a manner that the fluid which was driven out of the first would be received by the second, and what was driven out of the second would be received by the third, &c. and this constitutes what we now call an electrical battery.

But the most astonishing discovery which Franklin, or I might say any other person, ever made in this branch of science, was the demonstration of what had been slightly suspected by others, the perfect similarity, or rather identity, of lightning and electricity. The Doctor was led to this discovery by comparing the effects of lightning with those of electricity, and by reflecting, that if two gun-barrels electrified will strike at two inches, and make a loud report, what must be the effect of ten thousand acres of electrified cloud. Not satisfied, however, with speculation, he constructed a kite with a pointed wire fixed upon it, which, during a thunder storm, he contrived to send  
up

up into an electrical cloud. The wire in the kite attracted the lightning from the cloud, and it descended along the hempen string, and was received by a key tied to the extremity of it, that part of the string which he held in his hand being of silk, that the electric virtue might stop when it came to the key. At this key he charged phials, and from the fire thus obtained he kindled spirits, and performed all the common electrical experiments.

Dr. Franklin, after this discovery, constructed an insulated rod to draw the lightning from the atmosphere into his house, in order to enable him to make experiments upon it; he also connected with it two bells, which gave him notice by their ringing when his rod was electrified. This was the origin of the metallic conductors now in general use.

Mr. Canton afterwards discovered, that the positive and negative electricity, which were supposed to depend upon the nature of the excited body, and therefore had obtained the names of resinous and vitreous, depended chiefly upon the nature of the surface; for that a glass tube, when the polished surface was destroyed, exhibited proofs of negative electricity as much as sulphur or sealing wax, and drew sparks *from* the knuckle when applied to it, instead of giving fire from its own body; when the tube was greased, and a rubber with a rough surface was applied to it, its positive power was restored, and the contrary, when the rubber became smooth by friction.

At this period it may not be improper to close my sketch of the discoveries relating to electricity; since the sole object of these narratives, in this work, is to conduct the reader to a more ready apprehension of the science, it would be useless to lead him into the minutiae of it before he was made properly acquainted with the general principles.

## C H A P. II.

## GENERAL PRINCIPLES OF ELECTRICITY.

*Analogy between Caloric, or Fire, and the electrical Fluid.—The Arguments on the contrary Side.—Conjectures concerning the Nature of this Fluid.—Means of producing electrical Phenomena.—Conductors and Non-conductors.—Instruments employed in Electricity.*

**F**ROM the brief account, which has been given, in the preceding chapter, of discoveries relative to this extraordinary fluid, the reader will be in a considerable degree prepared to infer, that electricity is the action of a body put in a state to attract or repel light bodies placed at a certain distance; to give a slight sensation to the skin, resembling in some measure that which we experience in meeting with a cobweb in the air; to spread an odour like the phosphorus of Kunkell; to dart pencils of light from the surface, attended with a snapping noise, on the approach of certain substances; lastly, that the body put in this state is capable of communicating to other bodies the power of producing the same effects during a certain time.

The electric power is indubitably the effect of some matter put in motion, either within or round

the electrified body, since if we place either our hands or face before an excited tube of glass, or before an insulated conductor which is electrified, we shall perceive emanations sensible to the touch, and if we approach nearer, we shall feel it distinctly, and hear a weak noise; in the dark we perceive sparks of vivid light, especially from angular points; we see emitted pencils of rays, or small flashes of divergent flame; it is certain, therefore, that some subtle matter put in motion is alone capable of making these impressions upon our senses; and we may conclude, that every electrified body is encompassed by some matter in motion, which is, without doubt, the immediate cause of all the electrical phenomena, and which we term the electric matter or fluid.

Thus far, and no farther, are we warranted in affirming, on the only evidence to be admitted in philosophy, that of experiment, fact, and observation. There is, however, in man, a curiosity that prompts us to look beyond effects, and a disposition that leads us to theorize, even on the most difficult subjects. Let us, however, do it with diffidence and caution. What then is this electric matter? or whence does it derive its origin? It apparently proceeds not from the electrified body, for that suffers no sensible diminution. It depends not on any property inherent in the air of the atmosphere, for three obvious reasons; first, that electrical phenomena may be produced in a space from which the air has been most carefully exhausted. Secondly,  
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ly, Because the electrical matter has qualities which are not inherent in air; it penetrates certain bodies impervious to air, such as metals; it has a sensible odour; it appears itself inflamed; it is capable of inflaming other bodies, and of melting metals; effects which air cannot produce. Thirdly, It transmits its motions with considerably more rapidity than that of sound, which is a motion of the air the most rapid that we are acquainted with.

It is generally agreed, that the electric matter has a strong analogy with the matter of heat and light. It appears indeed, that nature; who is so very economical in the production of principles, whilst she multiplies their properties so liberally, has in no case established two causes for one effect. We may apply this remark to the electric matter; and the more we inquire into the properties of the electric matter, and those of the matter of heat and light, the more shall we discover of this analogy between them, and the more probable will it appear, that fire, light, and electricity depend upon the same principle, and that they are only three different effects from the same matter or essence.

1st. Of all the means necessary to excite the matter of heat, there is none more efficacious than that which is most necessary to produce electricity, namely; friction. 2dly. As fire, or caloric, extends itself with more facility in metals and humid bodies than in any other species of bodies, so metals and water are conductors of electricity in the same manner as they are of heat, and, in general, the same

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conductors are found equally good for both. 3dly. Fire, or caloric, is the most elastic of all bodies, and is considered by most philosophers as the principal cause of that repulsion which takes place between the particles of bodies, of which the strongest instance has already been given in explaining the cause of fluidity; and to a similar cause the electric repulsion may be referred. 4thly. The pulse and perspiration of animals are increased by electricity as by the actual application of heat, and the growth of vegetables is promoted by it\*. 5thly. Actual ignition is produced by the electric fluid: thus it is a common experiment to fire spirit of wine by the electric spark; inflammable air is set on fire by the same means in the common electrical pistol; and even gunpowder may be exploded by a spark from a powerful conductor. 6thly. Metals are melted by electricity, and most inflammable substances are affected by it as by common fire, but in a weaker degree.† 7thly. The light emitted by the

\* Sir Benj. Thomson's experiments, Phil. Transf. vol. lxxvi.

† Mr. Kinnerley made a large case of bottles explode at once through a fine iron wire; the wire at first appeared red hot, and then fell into drops, which burned themselves into the table and floor, and cooled in a spherical form like small shot. Artificial lightning, from a case of about thirty-five bottles, will entirely destroy brass wire of one part in three hundred and thirty of an inch. Metals may also be revived by the electric shock; and Sig. Beccaria melted borax and glass by it. Priestley's Hist. Elect. vi. 341—343. Seeds of clubmoss (*lycopodium*) were fired by it; also aurum fulminans, ib. 343.

electrical



electrical apparatus has all the properties of that which is emitted from the sun, the composition differing in some respects, according to circumstances, as to the predominancy of certain rays, the light in different instances inclining to blue, red, white, &c. according to its intensity. 8thly: The motion of light is exceedingly rapid, whether it is reflected or refracted; in the same manner the electric fluid is found to move with almost infinite velocity, for it has been proved by experiments, that a cord twelve hundred feet long has become instantly electric in its whole extent\*. The Abbé Nollet has communicated the electric shock to two hundred persons at the same time, or at the least perceptible instant.

Notwithstanding these considerations, it must be confessed that there are some facts which seem to indicate that the electric fluid is not purely and simply the matter of heat or light unmixed with other substances; for 1st, we have observed, that the electric matter has the property of affecting the organs of scent, which belongs neither to light nor heat.

2dly. It is well known also, that an accumulation of the matter of fire or heat increases the fluidity of all bodies, and prevents them from congealing, whereas congealed fluids may be highly charged with electricity; nor does it appear to have the smallest effect in increasing their fluidity.

\* Memoires de l'Acad. des Sci. 1733, p. 247.

3dly. Heat spreads in every direction, whereas the electrical fluid may be arrested in its progress by certain bodies, which, on that account, have obtained the name of non-conductors. The Torricellian vacuum, on the contrary, affords a ready passage to the electric fluid, but is a bad conductor of heat \*.

4thly. Whenever the matter of heat penetrates bodies, it warms as well as expands them. The electric fluid does not produce these effects; bodies, however long they may be electrified, become neither hotter to the touch, nor more extended in dimensions.

5thly. The singular property of adhering to certain conductors, without diffusing itself to others, which may be even in contact with them; so observable in the electrical fluid, is a property not common to caloric, or elementary fire. Thus we have seen that spirits were fired by an electric spark drawn by a wire through the water of the Thames, and large pieces of iron wire have been heated red hot, while immersed in water, by an electrical explosion †.

6thly. With respect to the identity of light and electricity, it should also be recollected, that light pervades glass with the greatest facility, whereas that substance is penetrated by the electrical fluid only in certain circumstances, and with the utmost difficulty; if, therefore, it should be admitted that the

\* Sir Benj. Thomson's experiments above quoted.

† Ibid.

basis of the electric matter is radically the same with the matter of heat or light, it must also be admitted, that it retains some other matter in combination with it, of the nature of which we are as yet uninformed; and it is probably this combination of foreign matter which disables it, in ordinary cases, from penetrating glass. Let it, however, be carefully remembered, that all this is speculation and conjecture, and that we at present know nothing of a certainty concerning the electrical fluid, but some of its effects.

Electrical phenomena are produced by friction, and by communication. In general, bodies which electrify the best by friction electrify the worst by communication (except glass in certain circumstances) and on the contrary, substances which electrify the best by communication electrify the worst by friction. I shall begin with those experiments which gave rise to the principal technical terms made use of in this science.

If a dry glass tube is rubbed with a piece of dry silk, and light bodies, as feathers, pith balls, &c. are presented to it, they will be first attracted, and then repelled. The best rubber for a smooth glass tube is a piece of black or oiled silk, on which a little amalgam has been placed; sealing wax, rubbed with new and soft flannel, will produce the same effect. By this friction an agent or power is put in action, and this power is called the electrical fluid; a certain quantity of this fluid is supposed to exist latent in all bodies,

bodies, in which state it makes no impression on our senses, but when by the powers of nature or of art, this equilibrium is destroyed, and the agency of the fluid is rendered perceptible to the senses, then those effects are produced which are termed electrical, and the body is said to be electrified.

If a homogenous body is presented to the excited tube, so as to receive electricity from it, and the electricity remains at or near the end or part presented, without being communicated to the rest of the body, it is called a non-conductor or electric; but if, on the contrary, the electricity is communicated to every part, the body is called a conductor, or non-electric. A body is said to be *insulated* when it communicates with nothing but electrics.

A conductor cannot be electrified while it communicates with the earth, either by direct contact or by the interposition of other conductors, because the electricity is immediately conveyed away to the earth.

A mutual attraction is exerted between a body in a state of electricity and all non-electric bodies, which, if not large and heavy, will pass rapidly through the air to the electrified body, where they remain till they have, by communication, acquired the same state, when they will be repelled. If an uninsulated conductor is at hand, it will attract the small body when electrified, and deprive it of its electricity, so that it will be again attracted by the electrified body, and repelled as before, and will

continue to pass and repass between the two, till the electric state is entirely destroyed.

The following substances are reckoned among the principal conductors of the electric fluid:

Stony substances in general,

Lime-stone, marbles,

Oil of vitriol,

Allum,

Black pyrites,

Black lead in a pencil,

Charcoal,

All kinds of metals and ores,

The fluids of animal bodies,

All fluids, except air and oils.

Electric bodies, or those substances which emit this fluid, are the following:

Amber, jet, sulphur,

Glass, and all precious stones,

All resinous compounds,

All dry animal substances, as silk, hair, wool, paper, &c

M. Achard, of Berlin, has proved by experiment, that certain circumstances will cause a body to conduct electricity, which before was a non-conductor. The principal of these circumstances are the degrees of heat to which the body is subjected. This gentleman agrees in opinion with M. Fulcr, that the principal difference between conductors and non-conductors consists in the size of the pores of the constituent parts of the body.

It must be observed, that electrics and non-electrics are not so strongly marked by nature as to be defined with precision; for the same substance has been differently classed by different writers; besides, the electric properties of the same substance vary according to changes of circumstances; thus a piece of green wood is a conductor, and the same piece, after it has been baked, becomes a non-conductor; when it is formed into charcoal it again conducts the electric matter; but when reduced to ashes is impervious to it. Indeed, it might perhaps be generally said, that every substance is in a certain degree a conductor of this fluid, though some conduct it with much more facility than others.

The instruments used in electricity are of five kinds; first, tubes of glass, or cylinders of sealing wax; the second consist of a single winch or of a multiplying wheel, by means of which, globes, cylinders, and plates of glass, of sulphur, or of sealing wax, are made to turn round; thirdly, metallic conductors, or substances charged with humidity; fourthly, electric bottles, commonly called Leyden phials; fifthly, electric batteries.

The first electrical machine made use of was a tube of glass, which, being electrified by friction, was then put in a state to communicate electricity to other bodies. The best glass for this purpose is the fine white English crystal. The most convenient dimensions for these tubes are about three feet of length, twelve or fifteen lines of diameter, and quite a line of thickness. It is of little importance whether the  
tubes

tube is open or closed at the extremities; yet it is necessary that the air within should be in the same state as that without; for this reason the tube should at least be open at one end; but care must be taken lest dirt should be admitted into the inside, for that would considerably impede its effects. If, notwithstanding these precautions, the tube receives either dirt or moisture, some dry and fine sand should be introduced into the inside, and it should be afterwards cleaned out with fine dry cotton.

When it is intended to electrify a tube, it is only necessary to take the end in one hand, and to continue to rub the tube with the other hand from one end to the other until it affords marks of its being sufficiently charged with the electric fluid. This friction may be performed with the naked hand when it is dry and clean, otherwise with a piece of brown paper, or waxed taffeta. When the tube has been rubbed in this manner, the circumambient air being dry, if light substances are presented to it, they will be first attracted towards it and immediately afterwards repelled.

The electric fluid may be excited in nearly a similar manner, by rubbing a stick of sulphur or sealing wax.

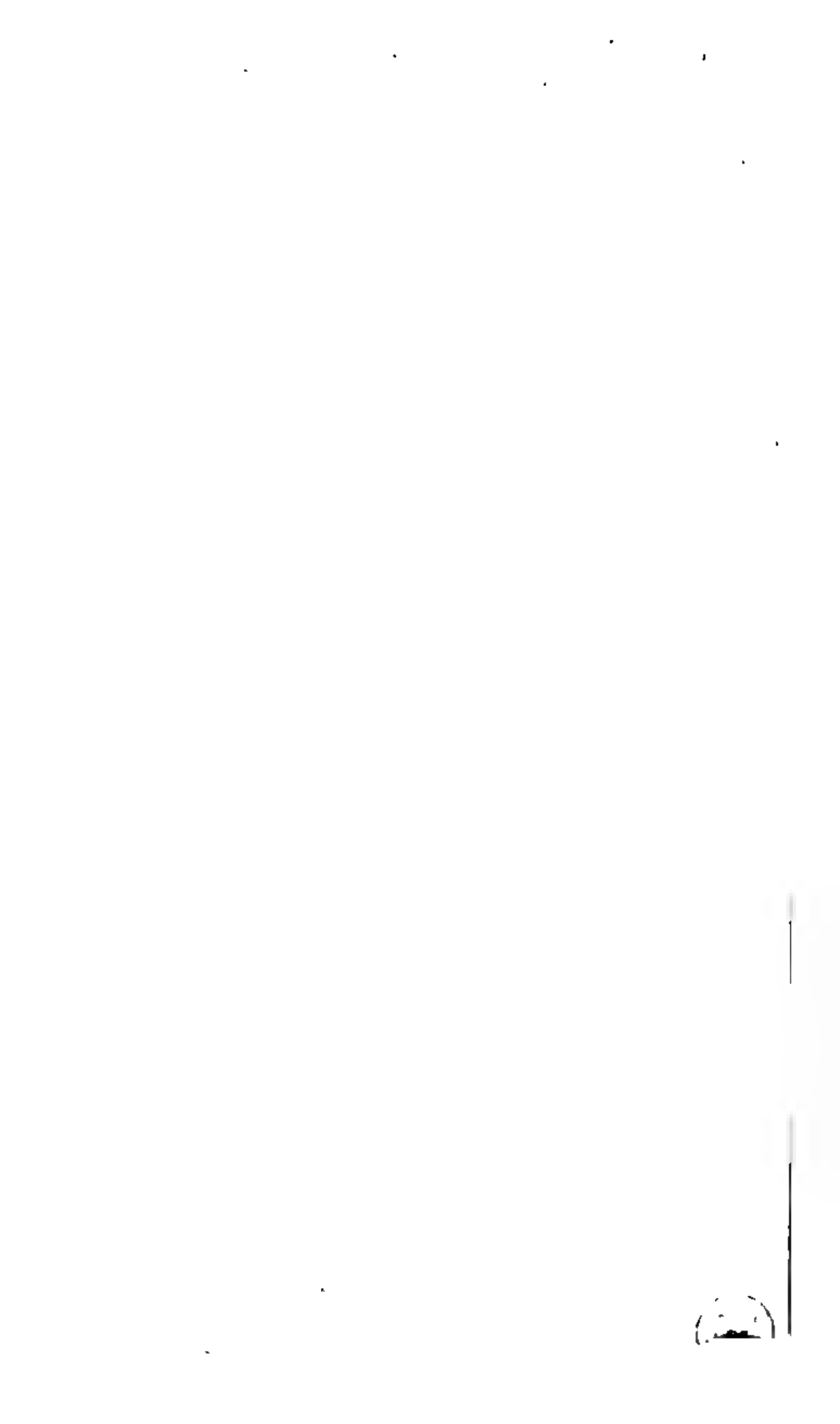
These tubes being but small, the electric fluid produced by these means is but feeble in its effects. We have seen that a method was contrived to turn a globe of glass upon its axis, by means of a machine with a winch or multiplying wheel; this method

thod admitted of a larger surface, and the friction was performed with greater ease, by means of a rubber being placed close to the revolving globe.

To construct a machine sufficiently large for all the purposes of electrical experiments, M. Briffon directs that the wheel R O (see Plate XVI. Fig. 1.) should be at least four feet in diameter, and be turned round in a strong and solid frame H I C D, &c. He directs further, that there should be two handles M, *m*, so that two men may be employed at once in certain cases, to give a sufficient friction to the globe to augment the effects. The globe S ought to be carried round between two small posts N, which ought to be so placed that they may be drawn farther from or nearer to the wheel, in order to admit the cord to be moved commodiously whenever it is contracted or extended. It is also necessary that one of these small posts should be moveable, that it may be placed either nearer to or farther from the other, so that globes of different diameters may be placed in the machine; the cord of the wheel R O should communicate immediately with the pulley P of the globe S.

When this machine is used for the purposes of electricity, the globe S should be turned according to the order of the cyphers 1 2 3, and its equator rubbed with a leathern cushion stuffed with horse hair, this may also be done by the hands when they are clean and dry. A bar of iron (A B, Fig. 2.) insulated with the cords of silk *s, s*, is placed over the  
the







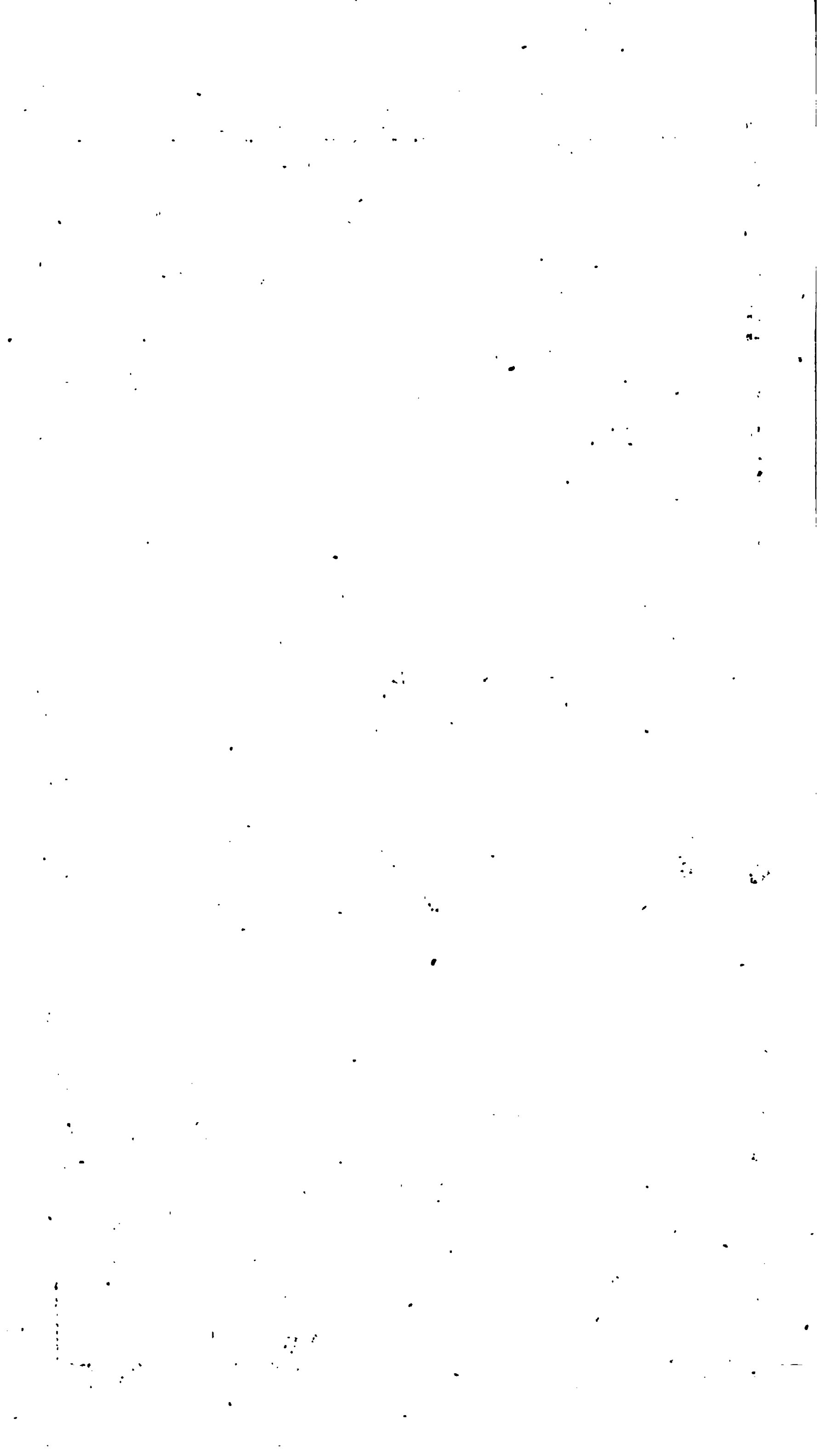


Fig. 3.



Fig. 1



1

g. 2.



the globe S, this bar serves as a conductor to the electric fluid \*.

A machine of a simpler construction has been invented in this country, and is represented in Plate XVII. Fig. 1. In this instrument a circular plate of glass is employed instead of a globe. The plate, P p, is bored through the center, and mounted on an axis, a a, of copper or hard wood, to which is fixed the handle, a b. The axis is supported by two vertical posts of wood, m, n, to which are appended four cushions, i i, formed according to the preceding directions, and which serve by their friction to excite the plate.

Before the plate a metal conductor, E D, is placed horizontally, having two arms or branches, A B, also of metal, each terminating in a small globe or knob, which may be brought within a convenient distance of the place to receive the electrical fluid. The conductor itself is insulated by two glass pillars, F G.

The advantages of this machine are, that it may be made portable, and is of so simple a construction, that any gentleman in the country, after procuring a plate of a reasonable thickness from a glass-house, may, by the aid of a common cabinet-maker, construct one for his own use; the conductor may be equally insulated by rosin, wax, silk, or any other electric or non-conducting substance.

\* Briffon, *Traité élémentaire de Phys.* tom. iii. p. 305.

This machine is, however, feeble in its operations, compared with those constructed with globes or cylinders. The most powerful, and yet the most simple, of these that I have seen, are those described by my late valuable friend, Mr. Adams, in his treatise of electricity.

Fig. 1. and 2, Plate XVIII. represent two electrical machines of the most approved construction; the only difference between them is, the mechanism by which the cylinder is put in motion.

The cylinder of the machine, Fig. 2. is turned round by two wheels, *a b*, *c d*, which act on each other by a catgut band, part of which is seen at *e* and *f*.

The cylinder in Fig. 1. is put in motion by a simple winch, which is less complicated than that with a multiplying wheel (Fig. 2.): as, however, both machines are so nearly similar, the same letters of reference are used in describing them both. A B C represent the bottom board of the machine, D and E the two perpendicular supports, which sustain the glass cylinder F G H I. The axis of the cap K passes through the support D; on the extremity of this axis either a simple winch is fixed, as in Fig. 1. or a pulley, as in Fig. 2 \*. The axis

\* Mr. Adams, in his Lectures on Nat. Philosophy, observes, that machines turned by a simple winch are less liable to be out of order than those which are turned by a multiplying wheel, and may also be excited more powerfully. *Adams's Lect.* vol. iv. p. 311.







of the other cap runs in a small hole, which is made in the top of the supporter E.

O P is the glass pillar to which the cushion is fixed; T a brass screw at the bottom of this pillar, which is to regulate the pressure of the cushion against the cylinder. This adjusting screw is peculiarly advantageous: by it the operator is enabled to lessen or increase gradually the pressure of the cushion, which it effects in a much neater manner than it is possible to do when the insulating pillar is fixed on a sliding board.

On the top of the pillar O P is a conductor, which is connected with the cushion, and this is called the negative conductor. In both figures this conductor is supposed to be fixed close to the cushion, and to lie parallel to the glass cylinder. In Fig. 1. it is brought forwards, or placed too near the handle, in order that more of it may be in sight, as at R S; in Fig. 2. the end R S only is seen.

Y Z (Fig. 1. and 2.) represents the positive prime conductor, or that which takes the electric fluid immediately from the cylinder; L M the glass pillar by which it is supported and insulated, and V X a wooden foot or base for the glass pillar. In Fig. 1. this conductor is placed in a direction parallel to the glass cylinder; in Fig. 2. it stands at right angles to the cylinder: it may be placed in either position occasionally, as is most convenient to the operator.

Previous to relating several circumstances, by which a large quantity of the electric fluid may be

excited, it may be necessary to premise, that the resistance of the air seems to be lessened, or a kind of vacuum is produced, where the cushion is in close contact with the cylinder; and that the electric matter, agreeably to the law observed by all other elastic fluids, is pressed towards that part where it finds least resistance; the same instant, therefore, that the cylinder is separated from the cushion, the fire issues forth in abundance, because the resistance made to it by the action of the atmosphere is lessened at that part: the effect which arises from the destruction of the attraction or cohesion between the cylinder and the cushion is a further proof of the truth of this hypothesis. The more perfect the continuity is made, and the quicker the solution of it, the greater is the quantity which will proceed from the cushion.

To excite, therefore, an electrical machine effectually, we must first find out those parts of the cushion which are pressed by the glass cylinder, then the amalgam must be applied to those parts only. The line of contact between the cylinder and cushion must be made as perfect as possible, and the fire which is collected must be prevented from escaping. The breadth of the cushion should not be great, and it should be placed in such a manner that it may be easily raised or lowered.

In order to find the line of contact between the cylinder and cushion, place a line of whiting, which has been dissolved in spirits of wine, on the cylinder; on turning this round, the whiting is deposited

†

on

on the cushion, and marks those parts of it which bear or rub against the cylinder. The amalgam is to be put on those parts only which are thus marked by the whiting.

Whenever the electricity of the cylinder grows less powerful, it is easily renewed by turning back the silk which lies over it, and then rubbing the cylinder with the amalgamated leather, or by altering the pressure of the adjusting screw.

A small quantity of tallow placed over the amalgam is observed to give more force to the electric powers of the cylinder; or the same end may be effected by rubbing the cylinder with a coarse cloth, which has been a little greased, and afterwards wiping the same with a clean cloth.

As air not only resists the emission of the electric fluid, but also dissipates what is collected, on account of the conducting substances which are floating in it, a piece of black or oiled silk should be placed from the line of contact to the collecting points of the prime conductor, and these points should be placed within its atmosphere.

Sometimes the silk will adhere so strongly to the cylinder, when zinc amalgam is used, as to render it very difficult to turn; this may be obviated by rubbing a small quantity of aurum musivum, or a little whiting, over the silk, when it is wiped clean\*.

There

• The following directions of Mr. Adams, relative to exciting the machine, will be useful to the experimentalist:

• To excite your machine, clean the cylinder, and wipe the silk,

There are now in use two kinds of amalgam : One is made of quicksilver five parts, zinc one part, which are melted together with a small quantity of bee's-wax ; the other is the aurum musivum of the shops. Before either of these will adhere closely to the silk it is necessary to grease it, to wipe off the superfluous grease, and then spread the amalgam.

One property of the electric fluid it will be proper to notice before the conclusion of this branch of the subject, and that is, that it is more forcibly attracted by points than by balls or any blunt or rounded surfaces. This may be demonstrated by a variety of easy experiments, and may be seen by presenting a metal ball at a given distance to a conductor in

‘ Grease the cylinder by turning it against a greasy leather, till it is uniformly obscured. The tallow of a candle may be used.

‘ Turn the cylinder till the silk flap has wiped off so much of the grease, as to render it semi-transparent.

‘ Put some amalgam on a piece of leather, and spread it well, so that it may be uniformly bright ; apply this against the turning cylinder, the friction will immediately increase, and the leather must not be removed until it ceases to become greater.

‘ Remove the leather, and the action of the machine will be very strong.

‘ The pressure of the cushion cannot be too small, when the excitation is properly made.

‘ The amalgam is that of Dr. Higgins, composed of zinc and mercury ; if a little mercury be added to melted zinc, it renders it easily pulverable, and more mercury may be added to the powder, to make a very soft amalgam. It is apt to crystallize by repose, which seems in some measure to be prevented by triturating it with a small proportion of grease : and it is always of advantage to triturate it before using.’

the

the act of being charged, when it will be found that a metal point presented at a much greater distance will draw off the whole of the electrical matter from the conductor. In the one case also (the point) the electricity goes off invisibly, and without noise; in the other case there is both a flash and a report.

With respect to the modes employed by electricians for the accumulation of the fluid, it will be necessary to consider them in a distinct chapter; but previous to this a few particulars must be stated relative to what is termed positive and negative electricity.

## CHAP. III.

OF THE VITREOUS AND RESINOUS,  
OR POSITIVE AND NEGATIVE ELECTRICITY.

*Distinction in the attractive Powers of certain Electrics.—Those Effects found to depend not on the Nature of the Substance, but the Roughness or Smoothness of the Surface.—Theory of Two distinct Fluids.—Franklin's Theory.—Difficulties attending it.*

**I**N a very early stage of the science, we have seen, that a distinction was observed with respect to the attractive and repulsive powers of certain electric bodies. Thus if we electrify with the same substance, for instance, either with excited glass or with sealing wax, two cork balls in an insulated state, that is, suspended by silk lines about six inches long, the balls will separate and repel each other; but if we electrify one of the balls with glass, and the other with sealing wax, they will be mutually attracted. This circumstance gave rise to the opinion, that two different species of electricity existed, and the one was termed the *vitreous* electricity, or that produced from glass; and the other, which was produced from sealing wax, resinous substances, and sulphur, was termed the *resinous* electricity.

Subsequent

Subsequent experiments served to shew, that in the common electrical machine, the rubber exhibited the appearances of the resinous electricity, and the cylinder, that of the vitreous, while the former was connected with the earth. A divergent cone or brush of electrical light was observed to be the obvious mark of the vitreous electricity, and a single globular mass of light distinguished the resinous kind. The hand or body also, which approached the vitreous or glassy substance, when excited, appeared to receive the matter from the electric; but when one of the resinous kind was excited, the electrical matter appeared to proceed from the hand or other approaching body.

Notwithstanding, however, the names by which these different forms of electricity were distinguished, as the vitreous and resinous, it was at length discovered, that the different phenomena depended rather upon the surface, than upon the nature and composition of the electric; for a glass tube, when the polished surface was destroyed, by being ground with emery, and being rubbed with a smooth body, exhibited all the proofs of the resinous electricity, as much as sulphur or sealing wax; yet afterwards, when it was greased and rubbed with a rough surface, it resumed its former property. It seems, therefore, to be a rule, that the smoothest of two bodies, upon friction, exhibits the phenomena of the vitreous electricity, for baked wooden cylinders with a smooth rubber are resinously electrified, but with a rubber of coarse flannel exhibit the appearances

ances of the vitreous kind; and even polished glass will produce the phenomena of the resinous electricity, if rubbed with the smooth hair of a cat's skin.

Amidst this embarrassing variety of experiments, those philosophers who applied to this branch of science, were eagerly employed in inventing theories to account for these phenomena, and electricians are still divided with respect to the cause.

The old theory of vitreous and resinous electricity, or two distinct, positive, and active powers, which equally and strongly attract and condense each other, has still its supporters; among the ablest of its defenders was my late friend Mr. Adams, who, it must be confessed, upon this theory, has ingeniously accounted for the most remarkable electrical phenomena \*.

The theory of Franklin, however, though not without its defects, has more simplicity, and accounts for facts in a more easy and more natural manner. The principles of this distinguished philosopher may be resolved into the following axioms:

1st. The electric matter is one and the same in all bodies, and is not of two distinct kinds.

2d. All terrestrial bodies contain a quantity of this matter.

3d. The electric matter violently repels itself, but attracts all other matter.

\* See Mr. Adams's Lectures on Nat. Phil. vol. iv.



4th. Glass and other substances, denominated electrics, contain a large portion of this matter, but are impermeable by it.

5th. Conducting substances are permeable by it, and do not conduct it merely over their surface.

6th. A body may contain a superfluous quantity of the electrical fluid, when it is said, according to this theory, to be in a *positive* state, or electrified *plus*; and when it contains less than its proper share it is said to be *negative*, or electrified *minus*.

7th. By exciting an electric, the equilibrium of the fluid is broken, and the one body becomes overloaded with electricity, while the other is deprived of its natural share.

Thus, according to the Franklinian theory, that electricity, which was before called vitreous, is now called *positive* electricity; and that which was termed the *resinous*, is now denominated *negative* electricity.

It is evident, that it is only in passing from one body to another, that the effects of the electrical fluid are apparent. When all the adjacent bodies therefore are equally charged with electricity, no effects whatever will appear. The equilibrium must, according to the principles of Dr. Franklin, be destroyed, that is, the fluid must be made rarer in some one part, before any of the phenomena will be exhibited. In that case the dense fluid rushing in to supply the deficiency in that part where it is rarer, produces the flash of light, the crackling noise, and the other effects of electricity.

The

The different effects on rough and smooth bodies, when excited, have been previously noticed. The Franklinian theory is, if a rough and smooth body are rubbed together, the smooth body will generally be electrified *plus*, and that with a rough uneven surface, *minus*. Thus, in the ordinary operation of the common machine, the cylinder is positively electrified, or plus, and the rubber negative, or minus. The redundance of the positive electricity is sent from the cylinder to the prime conductor, and may be communicated from it to any conducting body. If, however, the prime conductor is made to communicate with the earth, which has a great attraction for the electrical matter (and which, being one great mass of conducting substances, will not permit the accumulation of the fluid in a particular part) and if at the same time the rubber is in an insulated state, supported for instance by glass or any electric, these effects will be reversed, for the prime conductor will then be negatively electrified, and the rubber will be plus or positive.

This theory is, it must be confessed, not without its difficulties, and it is much to be feared, that we have as yet no complete theory of electricity. The fact most difficult to be explained on the Franklinian system is, that of two bodies negatively electrified repelling each other, for if the repulsion in the case of positive electricity is caused entirely, as there is reason to believe it is, by the electric matter, how should a deficiency of that matter produce the

the same effect? Attempts have been made to explain the fact by having recourse to the electricity of the air, which (when not charged with moisture) is certainly an electric or non-conducting substance, and in all cases is an imperfect electric. The cork balls, or other light substances, which are electrified negatively, are therefore supposed to be acted upon by the positive electricity of the air, which produces an effect adequate to their being positively electrified. This solution, however, is not quite satisfactory; though it is perhaps unphilosophical to reject an hypothesis, which explains some facts greatly to our satisfaction, merely because it has not as yet explained every thing.

Dr. Franklin supposed that the electric fluid is collected from the earth, and this hypothesis he supported by the following experiments.

Let one person stand on wax (or be insulated) and rub a glass tube, and let another person on wax take the fire from the first, they will both of them (provided they do not touch each other) appear to be electrified to a person standing on the floor; that is, he will perceive a spark on approaching either of them with his knuckle or finger; but if they touch each other during the excitation of the tube, neither of them will appear to be electrified. If they touch one another after exciting the tube, and draw the fire as before, there will be a stronger spark between them than was between either of them and the person on the floor. After such a strong spark neither of them discover *any electricity*.

He

He accounts for these appearances by supposing the electric fluid to be a common element, of which each of the three persons has his equal share before any operation is begun with the tube.

A, who stands upon wax and rubs the tube, collects the electrical fire from himself into the glass, and his communication with the common stock being cut off by the wax, his body is not again immediately supplied.

B, who also stands upon wax, passing his knuckle along the tube, receives the fire which was collected from A, and being insulated, he retains this additional quantity.

To the third person, who stands upon the floor, both appear electrified; for he, having only the middle quantity of electrical fire, receives a spark on approaching B, who has an over quantity, but gives one to A, who has an under quantity.

If A and B approach to touch each other, the spark is stronger, because the difference between them is greater. After this touch there is no spark between either of them and C, because the electrical fluid in all is reduced to the original equality. If ~~they~~ touch while electrifying, the equality is never destroyed, the fire is only circulating; hence we say that B is electrified positively, A negatively\*.

\* Mr. Adams on Electricity, p. 43.

## C H A P. IV.

## THE LEYDEN PHIAL, ELECTRICAL BATTERY, AND OTHER PARTS OF THE APPARATUS.

*Theory of the Leyden Phial.—Its Use in Electricity.—Description of the best Apparatus of this Kind.—The Charge resides in the Glass.—Curious Experiments with the Leyden Phial.—Electrical Battery.—Instructions relative to it.—Experiments with the electrical Battery.—Electrical Bells.—Electrophorus.—Electrometer.*

**I**N order to understand properly the nature of what is called the Leyden phial, or electrical jar, it will be necessary to revert to what has been said both in the introduction and in the preceding chapter on positive and negative electricity. If a piece of glass is coated with any conducting substance, it may be made to accumulate the electrical matter to a surprising degree. In this case one side of the glass, if it does not exceed a given thickness, will be positively electrified, and the other negatively. The form of the glass is of no consequence in this experiment; it may be either flat, cylindrical, or otherwise.

The object of the philosopher being, therefore, on many occasions, to collect a large quantity of electricity, by means of the surfaces of electrics, and,

as flat plates are neither necessary nor convenient for this purpose, he accommodates himself with a sufficient number of prepared jars. These are made of various shapes and magnitudes, but the most useful are thin cylindrical glass vessels, about four inches in diameter, and fourteen in height, coated within and without (except about two inches from the top) with tinfoil, or any other conducting substance.

If one side of this jar is electrified, while the other side communicates with the earth, it is said to be charged.

When a communication is formed from one side of the jar to the other by a conducting substance, after it has been charged, an explosion will take place, and this is called discharging the jar. This phial is incapable of being charged when it is insulated; that is, when neither side communicates with the earth. When it is charged, the two sides are in contrary states, the one being positively, the other negatively electrified.

A jar is said to be positively electrified when the inside receives the fluid from the conductor, and the outside is connected with the earth. It is negatively electrified when the outside receives the fluid from the conductor, and the inside communicates with the earth; but it is necessary that the jar charging negatively should be insulated, because the fluid is, in the first instance, conveyed to the coating, and would be immediately carried to the earth if it was not insulated.

The

The most usual forms of the Leyden phial are represented in Fig. 3. and 5. Plate XVII. and its nature may be exemplified by the following experiment :

Place the phial (Fig. 5.) on an insulated stand ; bring the coating in contact with the conductor ; turn the machine slowly, and after a few turns remove the phial from the conductor ; then form a communication between the outside and the inside of the phial, by placing one end of the discharging rod first upon the coating, and then bringing the other end of the rod to the brass ball of the bottle ; in this case there will be no explosion, because, both sides being insulated, the bottle was not charged ; but if a chain is suspended from the brass ball of the phial to the table, and the coating brought in contact with the conductor, after a few turns of the machine remove the phial as before ; then if the discharger is applied, an explosion will be heard, and the bottle will be discharged ; because, in this case, the insulation of the inside is destroyed by the chain, and the phial becomes capable of receiving a charge.

That the charge of a coated jar resides in the glass, and not in the coating, is proved in the following manner : place a plate of glass between two metallic plates, about two inches in diameter, smaller than the plate of glass ; charge the plate of glass, and then remove the upper metallic plate by an insulated handle ; take up the glass plate, and place it between two other plates of metal unelec-

trified and insulated, and the plate of glass thus coated afresh will still be charged. The following experiments are further illustrative of the nature of the Leyden phial.

A cork ball, or an artificial spider made of burnt cork, with legs of linen thread, suspended by silk, will play between the knobs of two bottles, one of which is charged positively, the other negatively, and will in a little time discharge them.

A ball suspended on silk, and placed between two brass balls, one proceeding from the outside, the other from the inside of a Leyden jar, when the bottle is charged, will fly from one knob to the other, and by thus conveying the fire from the inside to the outside of the bottle will soon discharge it.

An insulated cork ball, after having received a spark, will not play between, but be equally repelled by two bottles, which are charged with the same power.

A wire is sometimes fixed to the under part of the insulated coated phial (Fig. 5.) and *bc* is another wire fitted to, and at right angles with the former; a brass fly (Fig. 4.) is placed on the point of this wire; charge the bottle, and all the time the bottle is charging the fly will turn round; when it is charged the needle will stop. If the top of the bottle is touched with the finger, or any other conducting substance, the fly will turn again till the bottle is discharged. The fly will electrify a pair of balls positively while the bottle  
is



is charging, and negatively, when it is discharging \*.

When a Leyden phial positively charged is insulated, it will give a spark from its knob to an excited stick of wax, but not a spark will pass at that time between it and an excited glass tube.

An additional quantity of the fluid may be thrown on one side of the jar, if by any contrivance an equal quantity may be made to escape from the other, and not otherwise.

Electricians, in order to increase the force of the electric explosion, connect several Leyden phials together in a box; and this collection they call an electrical battery.

In this apparatus the bottom of the box (Plate XVII. Fig. 2.) is covered with tin-foil, to connect the exterior coatings; the inside coatings of the jars are connected by the wires *a, b, c, d, e, f*, which meet in the large ball *A*; *C* is a hook at the bottom of the box, by which any substance may be connected with the outside coating of the jars; a ball, *B*, proceeds from the inside, by which the circuit may be conveniently completed. Mr. Adams gives the following precautions to those who make use of an electrical battery †.

The top and uncoated part of the jar should be kept dry and free from dust; and after the explosion has taken place, a wire from the hook is to be connected to the ball, and left there till the bat-

\* Mr. Adams's Essay on Elect. p. 131.

† Ibid. p. 147.

tery is to be charged again, by which means the inconveniences arising from the frequent residuum of a charge will be obviated.

Every broken jar in a battery must be taken away, before it is possible to charge the rest.

It has been recommended, not to discharge a battery through a good conductor, if the circuit is not at least five feet long; but it must be observed, that in proportion to the lengthening of the circuit the force of the shock will be lessened.

Jars made of the green glass, manufactured at Newcastle, are said to endure an explosion without a probability of breaking.

If the spark from the explosion is concentrated, by causing it to pass through small circuits of non-conducting substances, the force of the battery will be considerably increased. For this purpose, cause the spark to pass through a hole in a plate of glass one twelfth or one-sixth of an inch diameter, by which means it will be more compact and powerful. By wetting the part round the hole, the spark, by converting this into vapour, may be conveyed to a greater distance, with an increase of rapidity, attended with a louder noise than common. Mr. Morgan, by attending to these and some other circumstances, has melted wires, &c. by the means of small bottles.

If the charge of a strong battery is passed through two or three inches of small wire, the latter will sometimes appear red hot, first at the positive side; and the redness will proceed towards the other end.

If

If a battery is discharged through a small steel needle, it will, if the charge is strong, communicate magnetism to the needle.

If the discharge of a battery passes through a small magnetic needle, it will destroy the polarity of the needle, and sometimes invert the poles; but it is often necessary to repeat this several times.

Dr. Priestley could melt nine inches of small iron wire at the distance of fifteen feet, but at the distance of twenty feet he could only make six inches of it red hot, so that we may infer from this, that notwithstanding their conducting power, still metals resist in some degree the passage of the electric fluid, and therefore in estimating the conducting powers of different substances, their length must not be forgotten.

If a slender wire is inclosed in a glass tube, and a battery discharged through this wire, it will be thrown into globules of different sizes, which may be collected from the inner surface of the tube; they are often hollow, and little more than the scoria or dross of the metal.

Dr. Watson and some other gentlemen made several curious experiments to ascertain the distance to which the electric shock might be conveyed, and the velocity of its motion, which were briefly noticed in the first chapter. In the first experiment, the shock was given, and spirits fired by the electric matter which had been conveyed through the river Thames. In another experiment, the electric fluid was made to pass through a circuit of

two miles, crossing the New River twice, going over several gravel pits and a large field, and afterwards conveyed through a circuit of four miles. This motion was so instantaneously performed by the electric fluid, that an observer, in the middle of a circuit of two miles, felt himself shocked at the same instant that he saw the phial discharged.

Notwithstanding this surprising velocity, it is certain, however, that both sides of a charged phial may be touched so quickly, even by the best conductors, that all the electric fluid has not time to make the circuit, and the phial will remain but half discharged; and there are several instances where the motion appears slow, and not easily reconcileable with the amazing velocity we have observed in the instance above: indeed it is certain, that this fluid is resisted in some degree in its passage through or over every substance.

There is another part of an electrical apparatus, originally of German invention, which, before the conclusion of that which may be called the mechanical part of electricity, it will be proper to notice. It is chiefly illustrative of the electrical attraction. This apparatus consists of three small bells, suspended from a narrow plate of metal; the two outermost by chains, and that in the middle, from which a chain passes to the floor, by a silken string. Two small knobs of brass are also hung, by silken strings, on each side of the *bell* in the middle, which serve for clappers. When this apparatus is connected with an electrified conductor, the outer-  
\*  
most

most bells, suspended by the chains, will be charged, attract the clappers, and be struck by them. The clappers, becoming electrified likewise, will be repelled by these bells, and attracted by the middle bell, and will discharge themselves upon it by means of the chain extending to the floor. After this they will be again attracted by the outermost bells, and thus, by striking the bells alternately, occasion a ringing, which may be continued at pleasure. Flashes of light will also be seen in the dark between the bells and the clappers; and if the electricity is strong, the discharge will be made without actual contact, and the ringing will cease.

If an apparatus of this kind is joined to one of those conducting rods, erected to protect buildings from the effects of lightning, it will serve to give notice of the approach and passage of an electrical cloud.

It is remarkable, that in certain cases bodies electrified will retain their electric power for almost any length of time, and on this principle a very ingenious instrument has been constructed, called an electrophorus. This machine consists merely of a mass of resinous matter, contained in a box for the convenience of carriage, and a plate of metal fitted to communicate with it, which is lifted by a handle of glass, or some non-conducting substance. The resinous mass being rubbed with a flannel, or even with the hand, and the plate of metal being applied to it, the metal will become

charged, and give out sparks very freely to any conducting body; and this property of communicating electricity the resinous mass will retain for a length of time, without any fresh application whatever.

To explain these phenomena it will be again necessary to recur to what has been said concerning negative and positive electricity; it will be necessary also to recollect, that the negative electricity was originally termed the *resinous*, because it was at first thought to be peculiar to those substances. In the electrophorus, therefore, the lower plate, or resinous mass, being negatively electrified, the matter is taken from the metal plate, and this becoming also negatively electrified, the fluid is attracted from any body which is presented to it.

Several instruments have been invented for measuring the quantity of electricity contained in any body. These generally are formed upon the principle of the electric attraction, and consist of a small pith ball, or other light body, suspended on a moveable arm, with a kind of semi-dial to mark the degrees. Mr. Adams recommends Mr. Henley's quadrant electrometer for this purpose, which he describes as follows: "It consists (Fig. 3. Plate XVI.) of a perpendicular stem formed at top like a ball, and furnished at its lower end with a brass ferrule and pin, by which it may be fixed in one of the holes of the conductor, as at Fig. 4. or at the top of a Leyden bottle. To the upper part of the stem, a graduated ivory semicircle is fixed,

+

about

about the middle of which is a brass arm or cock, to support the axis of the index. The index consists of a very slender stick, which reaches from the center of the graduated arch to the brass ferrule; and to it's lower extremity is fastened a small pith ball nicely turned in the lathe. When this electrometer is in a perpendicular position, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or less, according to the quantity of electricity."

## C H A P. V.

## GENERAL EFFECTS OF ELECTRICITY.

*Phenomena of Attraction and Repulsion.—Electrical Atmosphere.—  
 Different Effects on different Substances.—Electrical Cabeson.—  
 Experiments on Silk Stockings.—On the Evaporation of Fluids.—  
 —Vegetation.—Animal Perspiration.—Inflammation of Spirits.—  
 Animals killed by Electricity.—Curious Phenomena in vacuo.—  
 Recapitulation of Principles.*

THE various phenomena of electricity may, for the sake of perspicuity, be divided into two classes; the first of which may be included under the general head of attraction and repulsion; and under the second may be ranged all those phenomena which are accompanied with the luminous appearances, and that effect on the animal frame which is termed the electrical shock. Though some of these may appear at first to have very little analogy with the former class, yet we shall have frequent opportunities of inferring, that they are only necessary effects from one common cause, and rather differ in their circumstances than in their nature. The atmospherical phenomena will demand a distinct chapter.

It follows, from what has been already stated, that every body electrified, whether by friction, or by communication;



communication; whether by the means of glass, or any resinous substance; is surrounded by a kind of atmosphere of that fluid which is called the *electrical matter*.

The proof on which this hypothesis rests is, that light bodies are actually lifted up, and carried to or from the electrified body, which, the supporters of this theory alledge, could only be effected by their being enveloped in some fluid medium. Thus, when the hairs on the head of a person electrified stand erect, or the fibres of a soft feather spread out, as if to meet or recede from the conductor, according to circumstances, every particular hair or fibre is supposed to be surrounded with an electrical atmosphere.

It is demonstrated by Earl Stanhope, in his ingenious treatise on electricity, that the density of the electrical atmosphere diminishes exactly in proportion to the squares of its distance from the center of the electrified body.

Those attractions and repulsions, which we have seen take place when light bodies are brought near to electrified substances, are, agreeably to the notions of some philosophers, caused by two currents of the electric fluid; the current which departs from the bodies brought near to the electrified substance causes those bodies to appear to be attracted, and the current which departs from the electrified substance repels them: these two effects taking place in the same instant, we may infer that these two currents are simultaneous.

A body

A body repelled by an electrified substance will be attracted by this substance as soon as it has touched any non-electric body.

An electrified substance, if it is left free to move, is attracted by a non-electric body not electrified. Thus a small thin plate of metal, electrified and suspended by a thread of silk, is attracted either by a man's hand, a piece of green wood, or by a metal rod presented to it.

All substances are not attracted with equal force by electrified bodies ; in general those, which are in their texture the densest and most compact, are more readily attracted and repelled, and are subject to the influence of electricity at a greater distance than those which are looser and more porous in their consistence. A ribband or thread, when waxed or gummed, becomes more subject to this attraction and repulsion than it was in its original state. Of all substances, gold leaf appears the most easily affected by electrical attraction.

Electrified bodies adhere so closely together, that the circumstance has given occasion to a new term in philosophy, and it has been called the *electrical cohesion*. This fact was pleasantly illustrated by some experiments on silk stockings, communicated to the Royal Society by Mr. Robert Symner a few years ago. Two silk stockings, the one black and the other white, had been for some time upon one leg, and were then rubbed with the hand, and both pulled off together ; it appears that in this case the two stockings will adhere together in such a manner

as to require a considerable force to separate them. M. Briffon, who repeated the experiment, observes, that after he had separated the white from the black stocking another phenomenon occurred; for while he held them, one in each hand, suspended in the air, they swelled and puffed up as wide as if the leg had remained in them; when they were brought within ten or twelve inches of each other, they rushed precipitately upon one another, and adhered forcibly together; but this adhesion was not so great as that which took place while the stockings were one within the other. Mr. Symner supposed, that the success of this experiment depended upon the contrast between the black and white colour; but M. Briffon proves this hypothesis to be without foundation, having made the experiment by substituting for the black stocking another of a different colour, and even a white one; but he confesses, that when the experiment was made with two white silk stockings the effects were weak.

Electrical attraction appears not to be equally strong in vacuo as in the open air. From several experiments of Beccaria's we learn, that if the air is thoroughly exhausted out of a glass receiver, the attraction and repulsion of electrified light bodies within the receiver becomes languid, and soon ceases altogether.

Electricity augments the natural evaporation of fluids, and especially of those fluids which are most subject to evaporation of themselves; and it has also a great effect on fluids, when the vessels contain-  
ing

ing them are non-electrics. If a humid body, a sponge for instance, is placed upon a conductor positively electrified, the evaporation will go on much more rapidly, and it will be much sooner dry, than a similar body differently circumstanced.

Dr. Priestley also gives us reason to suppose, that plants, when electrified, vegetate earlier and more vigorously than those which have not been subjected to this influence.

That electricity increases the insensible perspiration of animals may be inferred from the circumstance that electrified animals are always lighter than those which are not.

The stream of electrical fluid has no sensible heat, but even appears cold to the touch; yet we have seen that the more inflammable bodies, and particularly spirit of wine, may be ignited by it. This experiment may be easily made by a spark from a common machine. Let a person insulated, and communicating with a charged conductor, hold in his hand a quantity of rectified spirit in a metal spoon. If the spirit has been a little warmed over a candle previously, the experiment will be more certain to succeed. Let another person then, not insulated, but communicating with the floor, present his finger to the spirit, a spark will immediately pass between the spoon and the finger, and the spirit will be inflamed. This phenomena might pass for an exertion of magic in an ignorant country, or an ignorant age.

By

By a smart shock of electricity from a charged phial, or a battery, small animals may be killed; but I have not understood that human art has yet been able to construct a battery large enough to kill an animal above the size of a sheep or a dog. The immediate or proximate cause of the death of animals by electricity, or by lightning, which is natural electricity, has not yet been ascertained. It was once supposed that the living principle was extinguished by the bursting of some blood vessel, from the violence of the shock; but a dog, which was killed by lightning, was carefully dissected, and none of the vessels found in the least injured. Becaria recovered some persons apparently struck dead by lightning; and when questioned with respect to the pain or suffering which they endured, they only complained of an unusual numbness or weariness in their limbs. The flesh of animals killed by electricity is rendered extremely tender, and is recommended by Dr. Franklin as an article of luxury. It will also putrify in a much shorter time than the flesh of those which are killed in any ordinary way.

The luminous effects of electricity are not precisely the same in vacuo as in the open air; and indeed a very curious phenomenon has been produced by injecting the electric light in a vacuum.

If a wire with a round end is fastened in an exhausted receiver, and presented to a conductor of an electrical machine, every spark will pass through the vacuum in a broad stream of light, visible the whole

**336 *Recapitulation of Doctrines and Facts*, [Book IV.**

whole length of the receiver, moving with regularity (unless it is turned back by some non-electric) and then dividing itself into a variety of beautiful rivulets, which are continually separating and uniting in a pleasing manner. When the vessel is grasped by the hand, a pulsation is perceived like that of an artery, and the fire inclines towards the hand. A small quantity of air is, however, necessary to occasion the greatest luminous effect.

The following is a recapitulation of what M. Brisson considers as fundamental principles, confirmed, he says, by his own experiments, seconded by those of other philosophers\*.

The electric fluid is the same in essence with that of light and heat, but combined with a substance which affects the organs of scent.

When bodies are electrified by glass, they furnish tufts or pencils of light; but if electrified by sulphur or resinous substances, they only produce points or sparks of light; bodies presented to those electrified by glass produce only luminous points, while those which are presented to bodies which are electrified by sulphur produce beautiful pencils or tufts of light.

To electrify bodies by communication, it is necessary to insulate them; the substances the most proper for this purpose are those which electrify the best by friction.

Glass, though it electrifies very well by friction, electrifies also by communication, even without any

\* *Traité Element. de Phys.* Tom. iii. p. 435.

preliminary preparation ; yet it is very proper to insulate.

Electrical phenomena are not produced entirely from the bodies upon which the electrifying machine acts ; the adjacent bodies or substances contribute towards their production.

The energy of the electric virtue is augmented, in conductors, more by an increase of surface, than by an augmentation of the mass.

Electrified bodies adhere one to another, so that they cannot be separated without a considerable effort, as was exemplified in the case of two silk stockings of various colours.

Electricity accelerates the evaporation of liquors, and the perspiration of animals.

The pencils or tufts of light, which are seen at the extremities or angles of electrified bodies, are always composed of divergent rays when they pass in the air ; but if a *non-electric* or conducting body is presented to them, they lose a great deal of their divergency ; their rays sometimes become even convergent, in order that they may approach towards that body which is more permeable than the air ; and if they are made to pass into a vacuum, they will assume the form of a large branch of light nearly cylindrical, or in the form of a spindle.

The spark which shines between two bodies is capable of setting combustible matters on fire.

## C H A P. VI.

## OF THUNDER AND LIGHTNING, METEORS, WATER-SPOUTS, &amp;c.

*Theory of Lightning.—Description of a Thunder Storm.—Observations relative to the Electricity of the Atmosphere.—Melting of Metals by the Cold Fusion a vulgar Error.—Conductors of Lightning.—How to be safe in a Thunder Storm.—Application of Electricity to other atmospherical Phenomena.—Rain.—Hail.—Snow.—Meteors.—Water-spouts.*

**I**T no longer remains a doubt among philosophers, that the cause which produces the effects of thunder is the same with that which produces the ordinary phenomena of electricity; the resemblance between them is indeed so great, that we cannot believe thunder itself to be any other than a grander species of electricity, naturally excited without the feeble efforts of human art. This fluid, probably, is diffused through the whole atmosphere at all times, either in a smaller or greater degree, and is occasionally perceptible to our senses, according to the concurrence of natural circumstances.

The cloud which produces the thunder and lightning may be considered as a great electrified body; but how has the cloud acquired its electric virtue? is the rational request of an inquisitive mind: and to satisfy this enquiry it will be necessary



sary to refer to what has been before observed, that this power is produced in bodies in two modes; by friction, and by communication. Bodies electrified by friction communicate their virtue to other bodies which are susceptible of it, being insulated, and at a convenient distance. As air, therefore, is an idio-electric body, it is not unphilosophical to suppose, that in stormy weather especially, when it is common to observe the clouds and the wind take contrary courses, a part of the atmosphere, rushing by the other, may cause the air to be electrified by the friction of its own particles, or by rubbing against terrestrial objects which it meets in its passage, or perhaps against the clouds themselves. It is probable also, that the inflammable substances, which arise and accumulate in the cloudy regions, contribute to increase the effects, not only of themselves, but, perhaps, still more, by the electric matter which they carry along with them. Another circumstance, which further inclines me to make this inference is, that thunder storms are more frequent and tremendous in those times and places, when and where we have reason to conclude that these exhalations are in the greatest abundance in the atmosphere, as in warm seasons and climates, as well as in those places where the earth is filled with substances capable of furnishing a large quantity of these exhalations, and in particular in the neighbourhood of volcanoes.

A cloud in a thunder storm may be considered as a great conductor, actually insulated and elec-

trified; and it may be supposed to have the same effect upon those non-electrics which it meets with in its course, as our common conductors have upon those which are presented to them. If a cloud of this kind meets with another which is not electrified; or less so than itself, the electric matter flies off from all parts towards this cloud; hence proceed flashes of lightning, and the formidable report of thunder.

‘Thunder storms,’ says Beccaria, ‘generally happen when there is little or no wind, and their first appearance is marked by one dense cloud, or more, increasing very fast in size, and rising into the higher regions of the air; the lower surface black, and nearly level, but the upper finely arched, and well defined. Many of these clouds seem frequently piled one upon another, all arched in the same manner; but they keep continually uniting, swelling, and extending their arches.

‘At the time of the rising of this cloud, the atmosphere is generally full of a great number of separate clouds, motionless, and of odd and whimsical shapes. All these, upon the appearance of the thunder cloud, draw towards it, and become more uniform in their shapes as they approach, till coming very near the thunder cloud, their limbs mutually stretch towards one another; they immediately coalesce, and together make one uniform mass. But sometimes the thunder cloud will swell, and increase very fast, without the conjunction of any of these adscititious clouds, the vapours of the atmosphere forming themselves into clouds where-  
ever

ever it passes. Some of the adscititious clouds appear like white fringes at the skirts of the thunder cloud, but these keep continually growing darker and darker as they approach or unite with it.

‘ When the thunder cloud is grown to a great size, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth. When the eye is under the thunder cloud, after it is grown larger, and well formed, it is seen to sink lower, and to darken prodigiously, at the same time that a number of small adscititious clouds (the origin of which can never be perceived) are seen in a rapid motion, driving about in very uncertain directions under it. While these clouds are agitated with the most rapid motions, the rain generally falls in the greatest plenty, and if the agitation is exceedingly great, it commonly hails.

‘ While the thunder cloud is swelling, and extending its branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes, between the cloud and the earth, in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues, the rarer the cloud grows, and the less dark is its

appearance, till at length it breaks in different places, and displays a clear sky.'

It is the opinion of the same author, that the clouds serve as conductors to convey the electric fluid from those places of the earth which are overloaded with it, to those which are exhausted of it.

To prove that the earth is often positively charged with respect to the clouds in one part while it is negative in another, he adverts to the fall of great quantities of sand, and other light substances, which are often carried into the air, and scattered uniformly over a large tract of country, when there was no wind to effect this phenomenon, and even when there was, they have been carried against the wind; he therefore supposes, that these light bodies are raised by a large quantity of electrical matter issuing out of the earth.

This comparatively rare phenomenon, he thinks, exhibits both a perfect image and demonstration of the manner in which the vapours of the atmosphere are raised to form thunder clouds. The same electric matter, wherever it issues, attracts to it, and carries into the higher regions of the air, the watery particles dispersed in the atmosphere. The electric matter ascends, being solicited by the less resistance it finds there than in the common mass of the earth, which at those times is generally very dry, and consequently highly electric. The uniformity with which thunder clouds spread themselves, and swell into arches, must be owing to their being affected by  
some

Some cause, which, like the electric matter, diffuses itself uniformly wherever it acts, and to the resistance they meet with in ascending through the air.

The same cause, which first raised a cloud from vapours dispersed in the atmosphere, draws to it those already formed, and continues to form new ones, till the whole collected mass extends so far as to reach a part of the earth where there is a deficiency of electric fluid; thither also they will be attracted, and thus the mass serves as a conductor. When the clouds are attracted in their passage by those parts of the earth, where there is a deficiency of the fluid, those detached fragments are formed, and also those uniform depending protuberances, which are probably the cause of water-spouts.

A wind always blows from the place whence a thunder cloud proceeds, and the wind is more or less violent in proportion to the sudden appearance of the thunder cloud, the rapidity of its expansion, and the velocity with which the adscitious clouds join it. The sudden condensation of such a prodigious quantity of vapour must displace the air, and agitate it on all sides.

In three states of the air, says the author above quoted, I could find no electricity in it. 1st. in windy weather. 2d. When the sky was covered with distinct and black clouds, which had a slow motion. 3d. In moist weather not actually raining.

In rainy weather, without lightning, his apparatus was always electrified a little time before the rain  
Z 4 fell,

fell, and during the time of rain, but ceased a little before the rain was over.

The higher his rods reached, or his kites flew, the stronger signs they gave of being electrified.

The clouds are sometimes positively, and sometimes negatively electrified. In the latter case the lightning is supposed, upon the Franklinian theory, to proceed from the earth to the cloud. The general effects of lightning are precisely the same with those of the electric shock, only greatly magnified. It may not be improper in this place to notice an old error, namely, the *melting of metals* by lightning, by what has been called the *cold fusion*. The error is found to rest upon certain ill attested relations of swords being melted in the scabbard by lightning, and money in the bag, without injuring the scabbard or the bag. A variety of experiments have been accurately made to determine the fact; the results of which have been, that the thin edge of the sword, or of the money, might have been instantaneously melted, and yet so instantaneously cooled, as neither to affect the scabbard nor the bag. A very small wire will instantly melt and instantly cool in the flame of a common candle.

Mr. Kinnesley inclosed a small wire in a goose quill filled with loose grains of gunpowder, which took fire as readily as if they had been touched by a red hot poker; tinder was kindled when tied to a piece of the same wire; but no such effects could be produced with a wire twice as large. Hence it appears, as Mr. Kinnesley remarks, that though the electrical  
fire

fire has no sensible heat when in a state of rest, it will, in passing through bodies, produce heat in them, provided they are proportionally small. Thus, in passing through the small wire, the particles are confined to a narrower passage, and, crowding close together, act with a more condensed force, and produce sensible heat\*.

The discovery of Dr. Franklin, which established the identity of lightning with the electrical fluid, suggested an invention, for which we are indebted to the same philosopher, for securing buildings from this most formidable enemy. The reader will perceive that I allude to that of metallic conductors.

Suppose Fig. 4. Plate XVI. to represent the gable end of a house, fixed vertically on the horizontal board *F G*; a square hole is made in the gable end at *b i*, into which a piece of wood is fixed; a wire is inserted in the diagonal of this little piece; two wires are also fitted to the gable end; the lower end of one wire terminating at the upper corner of the square hole, the top of the other wire is fixed to its lower corner; the brass ball on the wire may be taken off, in order that the pointed end may be occasionally exposed to receive the explosion.

Experiment.—Place a jar with its knob in contact with the conductor, connect the bottom of the jar with the hook *H*, then charge the jar, and bring the ball under the conductor, and the jar will be discharged by an explosion from the conductor to

\* Priestley's Hist. of Elect. p. 394.

the ball of the house. The wires and chain being all in connection, the fire will be conveyed to the outside of the jar without affecting the house; but if the square piece of wood is placed so that the wires are not connected, but the communication cut off, the electric fluid, in passing to the outside of the bottle, will throw out the little piece of wood to a considerable distance, by the lateral force of the explosion.

Unscrew the ball, and let the point which is underneath be presented to the conductor, and then you will not be able to charge the jar; for the sharp point draws the fire silently from the conductor, and conveys it to the coating on the outside of the jar.

The prime conductor in this experiment is supposed to represent a thunder cloud discharging its contents on a weather-cock, or any other metal, at the top of a building; and it may be inferred from this experiment, that if there is a connection of metal to conduct the electric fluid down to the earth, the building will receive no damage; but where the connection is imperfect, it will strike from one part to another, and thus endanger the whole building.

Elevated conductors, applied to buildings to secure them from lightning, will in this manner discharge the electricity from a cloud that passes over them, and a greater quantity of the discharge will pass through a pointed conductor, than through one which terminates with a ball; but whether the discharge will be  
made



made by a gradual current, or by explosion, will depend upon the suddenness of the discharge, on the nearness and motion of the cloud, and the quantity of the electricity contained in it. If a small cloud hangs suspended under a large one loaded with electric matter, pointed conductors on a building underneath will receive the discharge by explosion, in preference to those terminated by balls, the small cloud forming an interruption, which allows only an instant of time for the discharge \*.

Viscount Mahon (now Earl Stanhope) has communicated to the public, in a treatise on this subject †, some essentials to be observed in the erection of conductors to buildings; he advises, that the upper fifteen or twenty inches of the rod should be composed of copper, and not of iron, as the latter, being exposed to the weather, will rust, and rust does not conduct electricity; that the iron part of the rod should be painted, but not the upper part of it, because paint is no conductor. He further advises, that the upper extremity of a conducting rod should not only be accurately pointed and finely tapered, but that it should be extremely prominent, about ten or fifteen feet above all the parts of the building which are the nearest it. It may be added, that a conductor should always be carried in the earth some feet beyond the foundation of the building, and should, if possible, terminate in water.

\* Mr. Adams's Essay on Elect. p. 186.

† Principles of Electricity, p. 205.

The safest place during a thunder storm is the cellar; for when a person is below the surface of the earth, the lightning must strike it before it can reach him, and will of course, in all probability, be expended on it. Dr. Franklin advises persons apprehensive of lightning to sit in the middle of a room, not under a metal lustre, or any other conductor, and to lay their feet up upon another chair. It will be still safer, he adds, to lay two or three beds or mattresses in the middle of the room, and, folding them double, to place the chairs upon them. A hammock suspended by silk cords would be an improvement upon this apparatus. Persons in fields should prefer the open parts to the vicinity of trees, &c. The distance of a thunder storm, and consequently the danger, is not difficult to be estimated. As light travels at the rate of 72,420 leagues in a second of time, its effects may be considered as instantaneous within any moderate distance. Sound, on the contrary, is transmitted only at the rate of 1,142 feet, or about 380 yards in a second. By accurately observing therefore the time which intervenes between the flash and the noise of thunder which follows it, a very near calculation may be made of its distance, and I know no better means of removing unnecessary apprehensions.

The success of Dr. Franklin, in ascertaining the cause of thunder and lightning, induced succeeding philosophers to apply the same theory to the explanation of the other atmospherical phenomena. From a number of observations, the indefatigable Becca-

ria endeavours to account for the rising of vapours and the fall of rain, upon electrical principles; and, it must be confessed, that if it is not a primary agent in these effects, it would be rashness entirely to deny its influence. This philosopher supposes, that previous to rain a quantity of electric matter escapes from the earth, and in its ascent to the higher regions of the air collects and conducts into its path a great quantity of vapours. The same cause that collects will condense them more and more, till in the places of the nearest intervals they come almost into contact, so as to form small drops, which, uniting with others as they fall, come down in rain. The rain he supposes to fall heavier in proportion as the electricity is more vigorous.

Hail, he supposes to be formed in the higher regions of air, where the cold is intense, and where the electric matter is very copious. In these circumstances, a great number of particles of water are brought near together, where they are frozen, and in their descent collect other particles; so that the density of the substance of the hail-stone grows less and less from the center, this being formed first in the higher regions, and the surface being collected in the lower. Agreeably to this, it is observed, that on mountains, hail-stones as well as drops of rain are very small, there being but a small space through which they can fall.

Clouds of snow differ in nothing from clouds of rain, but in the circumstance of the cold which freezes them. Both the regular diffusion of snow,  
and

and the regularity of the parts of which it consists, shew the clouds of snow to be actuated by some uniform cause like electricity \*.

Consistent with this theory is the fact, that vapours never rise to a great height without producing meteors. Almost all volcanic productions are accompanied with lightning. The column of vapour, which proceeds from the bowels of a volcano, is continually traversed by lightning, which sometimes seems to proceed from the higher regions, sometimes from the column itself. These lightnings were observed by the younger Pliny, in the eruption which killed his uncle; and Sir William Hamilton has observed them several times. The aurora borealis is also generally supposed to be electrical; its light seems to be produced by the electric fluid, while it is condensed in passing in the columns of elevated vapour †.

It

\* Priestley's Hist. Elect. vol. i.

† Mr. Adams's description of this meteor, in his Lectures, is as follows: 'The appearances of the aurora come under four different descriptions. 1st, A horizontal light, like the morning aurora, or break of day. 2dly, Fine, slender, luminous beams, well defined, and of dense light. These often continue a quarter, an half, or a whole minute, apparently at rest, but oftener with a quick lateral motion. 3dly, Flashes pointing upward, or in the same direction as the beams, which they always succeed. These are only momentary, and have no lateral motion; but they are generally repeated many times in a minute. They appear much broader, more diffuse, and of a weaker light than the beams: they grow gradually fainter till they disappear; and sometimes continue  
for

It was intimated that water-spouts were among the phenomena, which some philosophers have attempted to explain on electrical principles. A water-spout is a most

for hours, flashing at intervals. 4thly, Arches, nearly in the form of a rainbow: these, when complete, go quite across the heavens, from one point of the horizon to the opposite point.

When an aurora happens, these appearances seem to succeed each other in the following order: 1. the faint rainbow-like arches; 2. the beams; and, 3. the flashes. As for the northern horizontal light, it appears to consist of an abundance of flashes, or beams, blended together by the situation of the observer.

The beams of the aurora borealis appear at all places to be arches of great circles of the sphere, with the eye in the center; and these arches, if prolonged upwards, would all meet in one point.

The rainbow-like arches all cross the magnetic meridian at right-angles. When two or more appear at once, they are concentric, and tend to the east and west; also the broad arch of the horizontal light tends to the magnetic east and west, and is bisected by the magnetic meridian; and when the aurora extends over any part of the hemisphere, whether great or small, the line separating the illuminated part of the hemisphere from the clear part, is half the circumference of a great circle crossing the magnetic meridian at right-angles, and terminating in the east and west: moreover, the beams, perpendicular to the horizon are only those on the magnetic meridian.

That point in the heavens to which the beams of the aurora appear to converge, at any place, is the same as that to which the south pole of the dipping needle points at that place.

The beams appear to rise above each other in succession; so that of any two beams, that which has the higher base has also the higher summit.

Every beam appears broadest at or near the base, and to grow narrower as it ascends; so that the continuation of the bounding

most formidable phenomenon, and is indeed capable of causing great ravages. It commonly begins by a cloud, which appears very small, and which mariners call the squall, which augments in a little time into an enormous cloud of a cylindrical form, or that of a reversed cone, and produces a noise like an agitated sea, sometimes emitting thunder and lightning, and also large quantities of rain or hail, sufficient to inundate large vessels, overset trees and houses, and every thing which opposes its violent impetuosity.

These water-spouts are more frequent at sea than by land, and sailors are so convinced of their dangerous consequences, that when they perceive their approach, they frequently endeavour to break them by firing a cannon before they approach too near the ship. They have also been known to have committed the greatest devastations by land; though, where there is no water near, they generally assume the harmless form of a whirlwind.

In accounting for these phenomena upon electrical principles, it is observed, that the effluent matter proceeds from a body actually electrified towards one which is not so; and the affluent matter proceeds from a body not electrified towards one which is actually so. These two currents occasion

bounding lines would meet in the common center to which the beam tends.

‘ The height of the rainbow-like arches of the aurora are estimated by Mr. Dalton to be above the earth’s surface about 150 English miles.’ Adams’s Lectures, vol. iv. p. 542.

two motions analagous to the electrical attraction and repulsion. If the current of the effluent matter is more powerful than the affluent matter, which in this case is composed of particles exhaled from the earth, the particles of vapours, which compose the cloud, are attracted by this effluent matter, and form the cylindrical column, called the *descending water-spout*; if, on the contrary, the affluent matter is the strongest, it attracts a sufficient quantity of aqueous particles to form gradually into a cloud, and this is commonly termed the *ascending water-spout*.

A different explanation of these phenomena has been, however, given by other philosophers, and to this it will be proper to advert in the succeeding book, which treats of the nature and properties of air \*. In the mean time I shall add a short description

\* Mr. Nicholson, who has given both theories, has the following observations, which greatly strengthen the hypothesis which ascribes these phenomena to electricity:—‘ It was observed of water-spouts, that the convergence of winds, and their consequent whirling motion, was a principal cause in producing that effect; but there are appearances, which can hardly be solved by supposing that to be the only cause. They often vanish, and presently appear again in the same place: whitish or yellowish flames have sometimes been seen moving with prodigious swiftness about them, and whirlwinds are observed to electrify the apparatus very strongly. The time of their appearance is generally those months which are peculiarly subject to thunderstorms, and they are commonly preceded, accompanied, or followed by lightning, the previous state of the air being alike in both cases. And the long established custom, which the sailors

tion of one of these wonderful appearances, as given by the celebrated M. Tournafort in his Voyage to the Levant.

“ The first of these,” says this traveller, “ that we saw, was about a musket-shot from our ship. Then we perceived the water began to boil, and to rise about a foot above its level. The water was agitated and whitish; and above its surface there seemed to stand a smoke, such as might be imagined to come from wet straw before it begins to blaze. It made a sort of a murmuring sound, like that of a torrent heard at a distance, mixed, at the same time, with an hissing noise, like that of a serpent: shortly after we perceived a column of this smoke rise up to the clouds, at the same time whirling about with great rapidity. It appeared to be as thick as one’s finger; and the former sound still continued. When this disappeared, after lasting for about eight minutes, upon turning to the opposite quarter of the sky, we perceived another, which began in the manner of the former; presently after a third appeared in the west; and instantly beside it still another arose. The most distant of

have, of presenting sharp swords to disperse them, is no inconsiderable circumstance in favour of the supposition of their being electrical phenomena. Perhaps the ascending motion of the air, by which the whirling is produced, may be the current known to issue from electrified points, as the form of the protuberance in the sea is somewhat pointed; and the electrified drop of water may afford considerable light in explaining this appearance.’—*Nicholson’s Philosophy*, vol. ii. p. 361.



these three could not be above a musket-shot from the ship. They all continued like so many heaps of wet straw set on fire, that continued to smoke, and to make the same noise as before. We soon after perceived each, with its respective canal, mounting up in the clouds, and spreading, where it touched the cloud, like the mouth of a trumpet, making a figure, to express it intelligibly, as if the tail of an animal were pulled at one end by a weight. These canals were of a whitish colour, and so tinged, as I suppose, by the water which was contained in them; for, previous to this, they were apparently empty, and of the colour of transparent glass. These canals were not strait, but bent in some parts, and far from being perpendicular, but rising in their clouds with a very inclined ascent. But what is very particular, the cloud to which one of them was pointed happening to be driven by the wind, the spout still continued to follow its motion, without being broken; and passing behind one of the others, the spouts crossed each other, in the form of a St. Andrew's cross. In the beginning they were all about as thick as one's finger, except at the top, where they were broader, and two of them disappeared; but shortly after, the last of the three increased considerably; and its canal, which was at first so small, soon became as thick as a man's arm, then as his leg, and at last thicker than his whole body. We saw distinctly, through this transparent body, the water, which rose up with a kind of spiral motion; and it sometimes diminished

a little of its thickness, and again resumed the same; sometimes widening at top, and sometimes at bottom; exactly resembling a gut filled with water, pressed with the fingers, to make the fluid rise, or fall; and I am well convinced, that this alteration in the spout was caused by the wind, which pressed the cloud, and impelled it to give up its contents. After some time its bulk was so diminished as to be no thicker than a man's arm again; and thus, swelling and diminishing, it at last became very small. In the end, I observed the sea which was raised about it to resume its level by degrees, and the end of the canal that touched it to become as small as if it had been tied round with a cord; and this continued till the light, striking through the cloud, took away the view. I still, however, continued to look, expecting that its parts would join again, as I had before seen in one of the others, in which the spout was more than once broken, and yet again came together; but I was disappointed, for the spout appeared no more."

## C H A P. VII.

## MEDICAL ELECTRICITY.

*Declaration of the Abbé Nollet on this Subject.—Mr. Adams an Advocate for Medical Electricity.—Mode of Application.—Diseases to which it may be applied.—Apparatus most proper for Medical Purposes.*

**T**HE declaration of Abbé Nollet, that he received more pleasure from discovering that the motion of fluids in capillary tubes, and the insensible perspiration of animated bodies, were augmented by electricity, than from any other discovery he had made, reflects the highest honour upon his character as a friend of mankind.

Mr. Adams, who was not inferior in humanity and philanthropy to the French philosopher, strongly contends for the medicinal effects of electricity, and brings to aid his arguments the acknowledged property in the electric fluid, to accelerate the vegetation of plants. We may indeed be convinced, by a variety of experiments, that the electric fluid is materially connected with the human frame, and is continually exerting its influence upon it. As the natural equilibrium of this fluid is easily destroyed in the human body, we may safely infer, that any alteration in the quantity or intensity of the ac-

tion of this powerful fluid will produce corresponding changes in the habit or health of the body. The following experiment proves the effect of this fluid upon organized bodies.

Let the charge of a large jar or battery pass from the head to the back of a mouse; if the shock is sufficiently strong, it will kill the animal. If the discharge is made in the same manner after its death, the fluid will pass visibly over the body, and not through it; from which circumstance we may infer, that the power or medium which transmitted the shock through the animal is lost with its life.

The late Dr. Cullen was of opinion, that electricity, when properly applied, is one of the most powerful stimulants that can be employed to act upon the nervous system of animals.

Mr. Adams, therefore, infers, from various experiments, that electricity is applicable to palsies, rheumatisms, intermittents; to spasm, obstruction, and inflammation. In surgery also, he adds, it has considerable effect. The gout, the scrophula, or king's evil, are ranked among those diseases to which this remedy is applicable; and there is reason to suppose, that in the beginning of these diseases its application has been very successful.

Modern electricians have contrived various modes for applying the electric fluid to the remedy of diseases.

The stream of this fluid may, without a shock, be made to pass through any part of the body; it  
may

may also be thrown upon, or extracted from, any part; and its action in each case may be varied, by causing the fluid to pass through materials which resist its passage in different degrees; it may be applied to the naked integuments, or to the skin covered with different resisting substances; and its power may be rarified or condensed, confined to one spot, or more diffused, as the discretion of the operator may direct him.

The apparatus the most proper for these medicinal operations are, an electrical machine with an insulated cushion, properly constructed to afford a continued and strong stream of the electrical fluid.

Mr. Adams has not only given a description and representation of this apparatus, but has also constructed them for public utility\*, upon a plan recommended by Mr. Birch in his lectures to medical practitioners.

The total want of experimental knowledge upon this subject utterly disables me from deciding upon the efficacy of this remedy. It is certainly a powerful agent in nature, but its effects are transient, and the ease with which the fluid is transmitted through the human body will probably operate against its producing a permanent effect. Thus far, however, may with truth be advanced, that it is a safe and easy remedy, and therefore should never be omitted where there is a chance of its doing

\* Adams's Essay, p. 313.

good. Medical men are, however, the only proper judges when it ought to be applied; and it should be a maxim, that the safest and most innoxious medicines may have the most fatal consequences in unskilful hands.

## B O O K V.

## O F A I R.

## CHAPTER I.

HISTORY OF DISCOVERIES RELATIVE  
TO AIR.

*Vague Notions of the early Chemists.—Van Helmont.—Chok and Fire Damp.—Mr. Boyle.—Discoveries of Dr. Hales.—Of Dr. Black.—Of Dr. Priestley.—Of Mr. Cavendish.—Of Lavoisier. Vital or dephlogisticated Air discovered by Dr. Priestley.—Composition of Water and of Nitrous Acid discovered by Mr. Cavendish.*

**T**HOSE aerial fluids, which in their nature and effects are different from the air of our atmosphere, did not escape the notice of the early chemists; but they paid little attention to the nature of them, contenting themselves with giving them a name which meant nothing, denominating them, in general, *spiritus sylvestris*.

Van Helmont distinguished them by the name of *gas*, which he defined to be a spirit or incoercible vapour, as the word *gas*, or rather *gheast*, in the Dutch language, signifies. He supposes the *gas* to have been retained by the substances  
from

from which it is extracted, in a fixed or concrete form. He asserts, that sixty-two pounds of charcoal contain sixty-one of gas, and only one of earth, and attributes the fatal effects which workmen experience occasionally in mines to the emanipation of this spirit. On the same principle he accounts for the eructations from the stomach and bowels, and for the floating of drowned bodies; and he concludes by determining, that this gas is a fluid of a nature quite different from that of our common air.

The existence of two different kinds of vapour, or elastic fluids, had been previously observed in mines, and coal-works: the one was observed to affect animals with a sense of suffocation, and to extinguish life, and it therefore obtained the name of the *choak-damp*; the other, from the dangerous property of catching fire when a candle or any ignited body was brought in contact with it, was termed the *fire-damp*.

A specimen of the fire-damp, or inflammable air, was collected from a coal-mine of Sir James Lowther, in Cumberland, and brought up in bladders to be exhibited to the Royal Society at London, in the year 1733; and in the year 1736 Mr. John Maud procured, from the solution of iron in oil of vitriol, a quantity of the very same species of inflammable air, and demonstrated that the same might be procured from most of the metals in certain circumstances.



The experiments of Van Helmont were greatly improved upon by the sagacious Boyle. He changed the name of gas to that of *artificial air*; he demonstrated, that this *artificial air* was not always the same; for instance, that the air produced by fermentation is essentially different from that which is formed from the explosion of gunpowder. He was, I believe, the first who perceived that the volume of air was diminished by the combustion of certain substances.

This last observation of Mr. Boyle seems particularly to have attracted the attention of the indefatigable Dr. Hales, and he invented instruments for determining the quantities both of the air, which was on some occasions produced, and on other occasions absorbed, by different substances. These experiments deserve the attention of every philosopher, and for accuracy or ingenuity have never been exceeded \*.

Among other circumstances, which were particularly remarked by Dr. Hales, was the great quantity of air contained in the acidulated mineral waters; and to this air he suspected they were indebted for their sparkling and brightness, and some other of their peculiar qualities. In observing the absorption of air by bodies in combustion, he saw that this absorption had its limits; he remarked also, in some cases, the alternate production and absorption of air, as for instance in respect to the air which he

\* See Hales's *Vegetable Statics*, *passim*.

produced

produced from the burning of nitre, which air, he observed, was very soon diminished in bulk, though he did not perceive that the absorption was owing to the water, which he always used in his experiments. The production of an air capable of inflammation from the distillation of certain substances did not escape his observation; and he has advanced, that the augmentation of weight in the metallic calces was in some degree owing to the air which they imbibed. That the phosphorus of Homberg diminishes the air in which it is burned; that nitre cannot explode in vacuo; and that air is in general necessary to the crystallization of salts, are among the facts which are noticed by this philosopher.

From the uncertainty, however, of Dr. Hales and his predecessors, with regard to several material circumstances, of which they appear to have had some casual glimpses, and from their total ignorance of others, the doctrine of the aerial fluids was but in a state of infancy; till the decisive experiments of Dr. Black, Mr. Cavendish, and Dr. Priestley, furnished us with a new system in this important department of natural history.

The first of these philosophers observed, that lime and magnesia, in their mild state, consist of an union of a certain aerial fluid with the earthy base; that this aerial matter is actually extracted by the operation of burning, which reduces ordinary calcareous earth to the state of quick-lime; and that it is afterwards re-absorbed by the quick-lime when exposed to the air. On this principle he was able,

not

not only to account for the loss of weight by the burning of lime-stone, but to estimate to the greatest nicety the additional weight which it could acquire from the atmosphere. He extracted the gas, to which he gave the name of fixed or fixable air, also by another process, namely, by dissolving the calcareous earth in acids; he found that the causticity of lime depended upon its violently attracting from vegetable and animal matter a portion of that air of which it had been deprived, and that upon this principle he was enabled to render caustic the alkaline salts.

To Mr. Cavendish the second place in the order of this history belongs. He pursued the experiments of Dr. Black, and ascertained the quantity of fixed air which could be retained by the fixed and volatile alkalis. He accounted for the nature of acidulated waters, by the fixable air which they contained. He procured a species of inflammable air from solutions of iron and zinc in vitriolic acid; and he was the first who remarked, that a solution of copper in spirit of salt, instead of yielding inflammable air, like that of iron or zinc, afforded a particular species of air, which lost its elasticity by coming in contact with water.

Dr. Priestley commenced his philosophical career by some experiments upon fixable air; and the first of his communications to the public related to the impregnating of water with this air, by means of chalk and oil of vitriol, a method first hinted by Dr. Brownrigg of Whitehaven, and now commonly  
 † practised

practised in the imitations of the acidulated mineral waters. The Doctor tried the power of fixable air upon animal and vegetable life, and found it fatal to both; and he made several other valuable experiments, the substance of which will be related in the chapter on fixed air.

The indefatigable mind of Dr. Priestley was not, however, to be satisfied with the investigation of a single object. He next turned his attention to the nature of atmospheric air. He observed, after Dr. Hales, its diminution by different processes, as by combustion, &c. but differs as to the cause. Dr. Hales supposed the specific gravity of the air to be increased; but Dr. Priestley judged, that the denser part of the air is precipitated, and that the remainder is actually made lighter. The discovery that the atmospheric air is purified by vegetation is also Dr. Priestley's.

On pursuing the experiments of Mr. Cavendish on inflammable air, the Doctor found that it was not only producible from iron and zinc, but from every inflammable substance whatever.

Dr. Priestley discovered the cause that air, which has been respired, becomes fatal to animal life, to be, that it becomes impregnated with something stimulating to the lungs, for they are affected in the same manner as when exposed to any other kind of noxious air. His experiments on the means of restoring salubrity to air are highly interesting and entertaining, and afford a pleasing instance of well-directed assiduity. But one of the most striking  
discoveries

discoveries of this philosopher is, that the nitrous air, which he procured from the solution of certain metals in the nitrous acid, had the property of diminishing a quantity of the purest part of the common air, the remainder being by this process rendered noxious and unfit for combustion; and upon this principle nitrous air was for a long time received as a test of the purity of the atmosphere, though it will afterwards appear that this test is imperfect. Dr. Priestley also pursued the last-mentioned experiment of Mr. Cavendish, and found that a simple acid, or alkali, might be made to assume the form of a permanently elastic fluid; and these fluids he distinguished by the title of *acid* and *alkaline airs*. But to specify all Dr. Priestley's discoveries, even in this very concise manner, would greatly exceed my limits; I must therefore be content with only cursorily mentioning the most remarkable.

The publication of these experiments of the English philosophers excited the attention of several ingenious foreigners; but the only discoveries worthy of notice in this place are those of M. Lavoisier. The experiments of this philosopher, ascertaining the precise quantity of water and elastic fluid, which are contained in slaked lime and mild alkali, also those upon the burning of phosphorus, are the neatest and most complete that have ever been published. The only new discovery of any note, which we can attribute to him, was, demonstrating that the reduction of metals is owing to the absorption of a certain elastic fluid; but he did not  
at

at first perceive that this fluid was in any respect different from the fixable air produced by effervescing mixtures. In a memoir, however, which he read, after the publication of his essays, before the French Academy, he is of opinion, that the air which is absorbed by the calcination of metals is common air, but that it is of the very purest kind, and more combustible and respirable than that in which we exist.

This opinion verges so closely upon the dephlogisticated, vital, or empyreal air of Dr. Priestley, that were we not informed by good authority, that M. Lavoisier first received from our English philosopher \* the hint of extracting air from *mercurius calcinatus*, the circumstance would in some measure affect the priority of his claim to that great discovery. Dr. Priestley confesses, that accident, rather than a preconcerted plan, was his guide upon this occasion. He had been employed in extracting air from different substances, and in particular in the conversion of the different acids into fluids permanently elastic. Among the substances from which he endeavoured to extract air was calcined mercury, which afforded it in considerable quantities; and upon applying the different tests, he found this air of a purer nature than the common atmospheric air. The air which was produced from red precipitate was equally pure with that which was afforded by the *mercurius calcinatus per se*. A similar product

\* Priestley on Air, vol. ii. p. 36, and 320.

was procured from red and white lead, from a variety of substances moistened with spirit of nitre; lastly, from common nitre itself, from sedative salt, and Roman vitriol. I omit noticing a number of erroneous opinions, which were started in the infancy of the science, as my present business is only to trace the steps by which our knowledge has been gradually improved in this department of nature.

Dr. Priestley continued his experiments on inflammable air, and found that all the metals which yield it when dissolved in acids, yielded it by means of heat alone; his mode of extracting it was by subjecting the filings of the different metals in vacuo to the action of a burning glass.

The next remarkable, and perhaps the most important discovery, was that of Mr. Cavendish, which has explained to us the nature and composition of water. Mr. Cavendish was led to this great discovery by the experiment of Mr. Warltire, related by Dr. Priestley, in which it was found, that on firing a mixture of common and inflammable air by the electric spark, a loss of weight always ensued, and that the inside of the vessel in which it was fired became always moist or dewy, though ever so carefully dried before. On repeating the experiment, Mr. Cavendish did not perceive the diminution of weight which Mr. Warltire supposed to take place, but the latter effect was completely exemplified. In prosecuting the experiment, it appeared, that it was only the pure or empyreal part, that is about one-fourth, of the common air which

was consumed, and the water produced was perfectly tasteless and pure ; on mixing empyreal air with the inflammable in a due proportion, the whole portion lost its elasticity, and was condensed into water.

Mr. Cavendish pursued his experiments with remarkable success, to ascertain the constituent principles of phlogisticated air, or that which constitutes the impure and unrespirable portion of the atmospheric air, and by passing the electric spark through common air, and through a certain mixture of empyreal and phlogisticated airs, he was able totally to condense the latter, and to ascertain its constituent principle to be the same with that of nitrous acid, with (as he then thought) a small portion of inflammable matter. In this latter opinion, however, he has since been corrected by Lavoisier, and other modern chymists, who have proved that azote, or phlogisticated air (as it is called by the English chemists) is no other than the basis of the nitrous acid \*.

On these experiments and discoveries the whole of the modern system of chemistry and physiology is founded; but their importance will be more completely proved, in treating more at large of the different species of air, and of the succeeding subjects, in these volumes.

\* In Mr. Cavendish's Experiment, as he probably used air which had been rendered impure by combustion, some small portion of charcoal or other inflammable matter might be contained in the air.



## CHAP. II.

OF OXYGEN GAS, OR PURE, VITAL,  
EMPYREAL, OR DEPHLOGISTICATED  
AIR.

*Explanation of Terms.—Reasons for the different Names assigned to this Fluid.—How procured.—From Calces of Metals.—By Vegetation.—From Water.—Properties of Oxygen.—A powerful Agent in the System of Nature.—How essential to Flame and Life.—Various Modes provided by Nature for furnishing a Supply of this Fluid.*

IT has been already intimated that *gas*, signifying spirit or ebullition, was a term employed by Van Helmont, and other Dutch and German chemists, to describe those elastic fluids, which appeared in their nature different from common or atmospheric air. From the preceding history of fire or caloric, the reader will be at no loss to understand, that every aeriform fluid consists of a *basis*, or matter peculiar to itself combined with the matter of heat, which is indeed the real efficient cause of all fluidity whatever. The word *gas* has therefore been employed by the French chemists to denote an aeriform fluid composed of a certain basis, which gives it its peculiar character, combined with the matter of heat or fire. It will be also proper to remember, that of those fluids which are termed

372 *Different Names assigned to this Fluid.* [Book V.]

elastic, some are permanently elastic, as the aeriform fluids, others, such as common vapour from water, are condensible by cold; and that it is only of the former kind that we have now to treat.

The fluid under our immediate consideration was originally termed *dephlogisticated* air, a name given it by Dr. Priestley from supposing it free from phlogiston or inflammable matter; when it was found essential to animal life, it obtained the name of *pure* or *vital air*; and when it was found to contribute essentially to ignition, and the other phenomena of fire, it was termed *empyreal* air; but the French chemists, having discovered that it is the substance which imparts the acid character to all the mineral and vegetable acids, have distinguished it by the name of *oxygen* \* *gas*.

Oxygen, or the base of oxygen gas, is naturally or artificially combined with a great variety of substances. From some of these it may be detached by the simple application of heat, since it has a remarkable attraction for the matter of fire, with which, when it unites, it becomes expanded, and assumes the form of gas or air.

The substances from which it may be most easily extracted, by means of heat, are red lead, calcined mercury, nitre, and manganese. Dr. Priestley exposed a quantity of red lead in the focus of a burning glass twelve inches in diameter. A quantity of

\* From  $\text{Oξυς}$  (oxus) "sharp or acid," and  $\gamma\epsilon\iota\omega\mu\alpha\iota$  (gine-mai) "to beget or produce."—Oxygen is then literally the principle or substance producing acids.

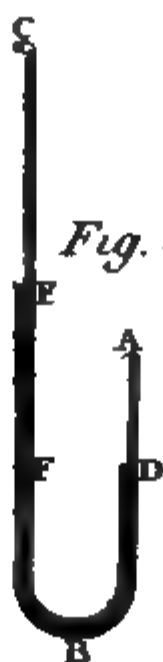


*Fig. 5.*

*Fig. 4.*

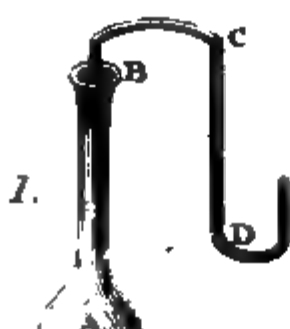


*Fig. 6.*



*Fig.*

*Fig. 1.*



*Fig.*



fixed air, or carbonic acid gas, as it is now called, was always produced at first; but after that was separated, the remainder was found to support flame, and to sustain animal life much more vigorously than common air, and to have all the characters of dephlogisticated air, or oxygen gas.

By various succeeding experiments of Dr. Priestley and others it however appears, that dephlogisticated air, or oxygen, may be obtained not only by means of heat, but also by the action of the vitriolic and nitrous acids upon a variety of mineral and metallic substances.

In a small phial A B (Plate XIX. Fig. 1.) to the mouth of which is fixed a bent tube C D, put an ounce of the oxid of mercury, or hydrargyrus calcinatus; put it to heat over the chaffing dish R; and after the atmospheric air, which filled the phial, is exhausted, place the extremity D of the bent tube under a long narrow glass vessel (Fig. 2.) filled with the fluid in the pneumatic apparatus or tub (Fig. 3.) and place this vessel upon the board E F above the aperture c or d\*.

As the mercury revives and becomes liquid, a compressible, elastic, transparent fluid may be observed to disengage itself, and pass into that narrow glass vessel; this is air of the purest kind that we are able to procure, namely, vital air or oxygen gas.

This kind of air may also be obtained by the

\* *Traité Elem. de Phys. tom. ii. p. 24.*

same process, from the native oxid or calx of manganese, or from minium or red lead, which, it is well known, is an oxid of lead united with nitrous acid.

The better to understand these effects it must be recollected, as was observed in the beginning of this chapter, that this fluid is not found in these substances in an entire state; they only contain the basis of it, which is the oxygen; for metals neither calcine nor burn but in consequence of their combination with oxygen, which by that means becomes solid, and joins its weight with theirs. This oxygen is then expelled by the heat or caloric, which, combining with it, causes it to pass into the state of an elastic fluid; during this process, the metal, losing the oxygen which had reduced it to the state of an oxid or calx, assumes its metallic properties, and loses the weight which it had acquired in becoming oxidated\*.

There is, however, a method by which oxygen gas may be obtained with less heat and greater facility, and it is as follows; put some red lead into a bottle, together with some good strong oil of vitriol, but without any water. Let the red lead fill about a quarter of the bottle, and the vitriolic acid be about the same quantity, or very little less; then apply the bent tube to the bottle by inserting it through a cork, and having inverted another bottle filled with water in a basin about half-

\* Brissot, tom. ii. p. 25.

filled also with water, direct the other end of the crooked tube into the bottle inverted in the water. In this stage of the process we must observe, that without heat this mixture of red lead and vitriolic acid will not afford any oxygen air, or a very inconsiderable quantity; it is necessary, therefore, to apply the flame of a candle or wax taper to the bottle containing the ingredients, while the crooked tube opens a communication between this bottle and that inverted in the water. In this manner the red lead will yield a quantity of elastic fluid, which will pass through the crooked tube into the inverted bottle, and as the quantity of dephlogisticated air increases in the inverted bottle, the water in it will be seen to subside; this air will not be all pure, because a considerable quantity of fixed air enters with it. In order to separate the fixed from the pure air, the inverted bottle, when filled with the compound of both, must be agitated in a basin of lime water, by which means the lime water will absorb the whole quantity of fixed air, and leave the dephlogisticated air or oxygen gas by itself.

Oxygen gas may also be obtained in considerable quantities from water, especially from pump water, which, when exposed to the sun, emits air slowly; but after it has remained so for a considerable time, a green matter adheres to the bottom and sides of the glass vessel in which it remained; afterwards it emits pure air in great quantities, and continues to do so for a long time after the green matter has exhibited symptoms of decay by turning yellow.

Dr. Ingenhoufz rightly supposed this green matter to belong to the vegetable kingdom, and procured pure air by putting the leaves of plants into water, and exposing them to the sun. He observes, that of land vegetables the fittest for this purpose are the poisonous plants, such as hyoscyamus, lauro-cerasus, night-shade, &c. But he extracted the purest air from some aquatic vegetables, and from turpentine trees, but especially from the green matter he collected from a stone trough, which had been kept filled with water from a spring near the high road.

While Dr. Priestley was engaged in a series of experiments to enable him to purify contaminated air, he discovered that vegetables answered this purpose most effectually. The experiment by which he illustrates his assertion was this; having rendered a quantity of air very noxious, by mice breathing and dying in it, he divided it into two receivers inverted in water, introducing a sprig of mint into one of them, and keeping the other receiver with the contaminated air in it alone. He found, about eight or nine days after, that the air of the receiver, into which he had introduced the sprig of mint, had become respirable; for a mouse lived very well in this, but died immediately upon being introduced into the other receiver, containing the contaminated air alone.

It has since been observed, that several animal substances, as well as vegetables, have a power of separating dephlogisticated air, or oxygen gas, from  
water,



water, when exposed to the action of the sun for a considerable time.

The ingenious count Rumford observes, that raw silk has a remarkable power of producing pure air. He found, that by introducing thirty grains of this substance, first washed in water, into a thin glass globe four inches and a half in diameter; having a cylindrical neck three-fourths of an inch wide and twelve inches long, inverting the globe into a jar filled with the same kind of water, and exposing it to the action of the sun in the window, in less than ten minutes the silk became covered with an infinite number of air bubbles, gradually increasing in size, till at the end of two hours the silk was buoyed up, by their means, to the top of the water. They separated themselves by degrees, and formed a collection of air in the upper part of the globe, which, when examined by the established test, appeared to be very pure. In three days he collected three and three-fourths of a cubic inch of pure air, into which a wax taper being introduced, that had just before been blown out, the wick only remaining red, it instantly took fire, and burned with a bright and enlarged flame. The water in the globe had acquired the smell of raw silk, it lost something of its transparency, and assumed a faint greenish cast.

It has been observed, that when this experiment was made in the dark, only a few inconsiderable bubbles were formed, which remained attached to the  
silk ;

filk; nor was it otherwise when the glass globe was removed into a German stove. In the latter case, indeed, some single bubbles had detached themselves from the filk, and ascended to the top; but the air was in too small a quantity to be either measured or proved.

In these experiments it is probable that the oxygen or pure air was extracted by an actual decomposition of a part of the water, by means of a capillary attraction, aided by the solar influence; and in effect the same philosopher was enabled to extract it, though in a smaller quantity, by means of a number of very minute glass tubes immersed in water and exposed to the sun.

The properties or functions of this fluid are some of the most important in nature; nor, except caloric or heat, is there any natural agent more universal or more active.

1st. It is essential to combustion; nor do we know of any process by which flame can be supported without a supply of oxygen gas, or empyreal air.

2dly. In certain proportions it is absolutely necessary to sustain animal life; so that the whole animal creation may be said to depend upon this fluid for their existence.

3dly. It is what gives the acid character to all mineral and vegetable salts, the bases of which are found to be entirely insipid till combined with oxygen.

4thly,

4thly. The calcination of metals is altogether effected by their union with oxygen. Thus for most of the mineral pigments, and a very numerous class of medicines, we are indebted to this useful element.

5thly. It forms a constituent part of that necessary fluid, water, which consists of 85 parts of oxygen, and 15 of hydrogen, or the basis inflammable air.

Oxygen gas, or air, is more elastic than common air; it exceeds it also in specific gravity, for the proportion between pure and common air is as 160 to 152.

On introducing a lighted candle into pure or dephlogisticated air, the flame becomes larger and brighter; and whenever the air is very pure, the candle burns with a crackling noise, as if the air contained some combustible matter, while the tallow or wax wastes, or is consumed, incredibly fast.

Philosophers have proved by various experiments, that common air is not diminished by burning; in all these experiments the quantity of vapour produced was equal to that absorbed, or otherwise made to disappear, during the operation. But the case is different with oxygen or dephlogisticated air; for if a burning candle is introduced into a glass jar filled with this kind of air, an intense heat will take place, which will at first expel a small quantity of the air; afterwards, when the candle is extinguished, it will be found that two-thirds of the bulk of air employed will be converted into fixed air. When the fixed air is taken up by caustic

caustic alkali, the small remainder will be as pure as before.

In common processes, not more than one-tenth of the air employed is converted into fixed air. It is probable, that in these experiments some diminution in the volume of air must take place, from the superior gravity of fixed air, and the consequent condensation of the other.

If live coals are introduced into a vessel filled with dephlogisticated air, it will be found to be diminished one-fourth of its quantity. When this experiment is repeated with sulphur, the flame will become larger and more vivid than in common air, and three-fourths of the quantity will be lost. If a piece of phosphorus is put into a seven ounce measure of this kind of air, the mouth of the bottle being corked, and the phosphorus being set on fire within it, the phial will break in pieces, as soon as the flame is extinguished, by the pressure of the external air.

The purity of vital air is ascertained by its degree of diminution with nitrous air, or gas obtained from nitrous acid, and this process is to be considered as a species of combustion, especially as a considerable degree of heat is generated by it. Very great differences, however, are perceived in this respect; and according to the quantity of diminution, the air is said to be two, three, or four times better than common air. Dr. Priestley mentions some extracted from red-lead five times as pure as common air.

Pure

Pure or oxygen air is not absorbed by water, nor soluble in it; but it may, as was just intimated, be almost entirely condensed by nitrous gas, with which it combines, as will be proved when treating of that substance; and this combination is soluble in water, and forms nitrous acid; for this acid is composed of the basis of nitrous gas combined with oxygen, the whole being dissolved in water.

The reason that pure air is the most essential of all the fluids to the support of life is, probably, because a great quantity of heat is necessary for this purpose, and because this fluid contains it in great quantity, and parts with it very freely when it meets with any substance with which it has an affinity. But as its basis (oxygen) combines itself very easily with the basis of coal which is found in the blood and lungs, and, during this combination, loses part of its caloric or heat, which goes to the support of life, the remainder of the caloric and oxygen, combined with the coal, form the acid carbonic gas or fixable air, which is always found to exist in a larger quantity in air which has been respired, than in atmospheric air which has not been subservient to that function. Of this a very easy experiment affords sufficient proof; it is founded on the property which the carbonic gas has of rendering lime-water turbid. A crooked tube open at both ends is partly filled with lime-water; a person applies his mouth to one end of the tube, and inspires, by drawing the air through the lime-water contained in it. By this the transparency of the lime-water is

is not affected; but it becomes turbid as soon as the person expires, which is owing to the carbonic acid formed in the lungs. It is therefore the great attraction which exists between the matter of coal and the basis of pure air which renders this fluid so proper for breathing. The pure air which we breathe performs two functions equally necessary to our preservation; it carries off from the blood that matter of coal, the superabundance of which would be pernicious, and the heat which this combination deposits in the lungs repairs the continual loss of heat which we experience from surrounding bodies. According to Dr. Priestley and others, the basis of oxygen gas is also absorbed by the blood.

Since, therefore, a great quantity of heat is disengaged from pure air in respiration, it follows, that this fluid must be very pernicious to animals who breathe this air alone for a considerable time; which is consonant with the observations of physicians, who have attempted to cure phthisis by the respiration of vital air.

The basis of this empyreal or pure air, or oxygen, as the French chemists term it, is one of the constituent parts of water. It has been mentioned, that it is also the matter which gives the acid character to all the acids; sulphur, for instance, is a very innoxious, insipid body, till by burning, that is by absorbing oxygen, it becomes vitriolic acid. Whether the basis of this empyreal air is a simple or compound substance, we are unable to determine;

mine ; in the present state, however, of philosophical knowledge, we are justified in considering it as a simple elementary body, for it has never yet been decomposed.

If the limits of this work permitted, or if the researches of philosophers had furnished us with sufficient materials, it would be a most pleasing speculation to trace the wisdom of Providence in the very ample means which he has provided for supplying us with this necessary fluid. It is evident, that immense quantities of it are, by the various processes of combustion, destroyed, or, to speak more philosophically, condensed, and by its union with inflammable matter formed into water. This water is again raised into the atmosphere in the form of vapour ; it falls in dew or rain upon the leaves of plants, and there, by the genial action of the solar rays, a new decomposition again takes place, and every branch, every leaf, every blade of grass, is occupied in the beneficial function of again impregnating the atmosphere with this salutary fluid. The quantities too, which are absorbed by the calces of metals, must be immense ; but by the various processes for the smelting and reduction of these metals, the oxygen is again set free, and a fresh supply is produced. Even the air, which is injured by respiration, is doubtless again, by a variety of modes, the greater part concealed from our view, purified, and rendered once more fit for use, since fixed air, in a disengaged state, is, comparatively speaking, but a rare substance in nature, and since there

there is reason to suppose that many of the carbonic bodies may be recruited also by its decomposition. Ignorance of nature is proverbially the sole source of atheism; and who can contemplate this astonishing revolution, this circulation of benefits, and not smile at the extreme folly of the man, who can suppose these appointments established without intelligence or design.



## CHAP. III.

AZOTIC\* GAS, OR PHLOGISTICATED  
AIR.

*Azotic Gas is the unrespirable Part of the Atmosphere.—How procured.—Air Bladders of Fishes filled with it.—Its Properties.—Azote the Basis of nitrous Acid.*

**T**HE azotic gas is called by Lavoisier mofete, and by Dr. Priestley phlogisticated air. It constitutes about three-fourths of the atmosphere, but is not respirable by itself; whence it derives the name of *azote*, as being unfit for the support of animal life. Philosophers have proved, that this fluid is completely formed in the atmosphere, and that it may be procured by merely absorbing or destroying the pure air, or oxygen, with which it is united in atmospheric air.

Azotic gas, therefore, is always found to remain after a quantity of common air has undergone the respiration of animals, the combustion of bodies, or putrefaction; because in all these cases the pure air

\* Or “air which takes away life,” from the Greek privative particle  $\alpha$  and  $\zeta\omega\eta$  (*zoê*) “life.” Dr. Priestley called it phlogisticated air, from supposing it chiefly composed of an imaginary substance, which Scheele and his followers termed phlogiston (or the food of fire); this appellation is now found to be erroneous.

is absorbed or condensed. Azotic gas is equally invisible with common air, and something more elastic. Mr. Kirwan procured some air, by means of a mixture of iron-filings and sulphur, so perfectly free from vital air, that it was not in the least diminished by the test of nitrous air. When this kind of air is so produced and dried, by introducing dry filtering paper under the jar that contains it, its weight will be found to be to that of common air as 985 to 1000, the barometer standing at 30.46, and the thermometer at 60°.

Various substances also are productive of this air; and M. Fourcroy has discovered, that the air bladders of fishes, and particularly of the carp, are full of it; and that it may be collected by breaking them under glass vessels inverted in water. The air, however, which is contained in the bladders of marine plants, is found to be considerably purer than atmospheric air.

In speaking of the properties of this fluid it is proper to remark, 1st. That azotic gas affords no sign of acidity, not being capable of turning the blue colours of vegetables red\*.

2d. It does not precipitate lime dissolved in water; for if a small quantity of lime water is put into a tube filled with this gas, it will remain clear and

\* The common test of chemists, to prove whether any fluid contains an acid. They commonly drop a small portion of the fluid into a clear phial containing syrup of violets; but the most delicate test is, a paper stained with tincture of turnsole or litmus, to which the acid is applied by a feather.

limpid;

limpid; there will be neither lime precipitated, nor chalk formed, which evinces that it is radically different from fixed or carbonic acid air.

3dly. Another property of this gas is that of suddenly extinguishing substances on fire, and killing animals which are plunged into it. This may be proved by introducing an animal, or a burning candle, into a vessel full of this gas; the animal will be suddenly suffocated, and the candle instantly extinguished.

4thly. Azotic gas is rendered respirable by vegetables, which, in certain circumstances, furnish vital air. This property is probably owing to their retaining the hydrogen of the water which they absorb, while they part with the oxygen. There is no doubt that azotic gas is really a constituent principle of the atmosphere; for if seventy-three parts of it are mixed with twenty-seven of pure air, an air will be produced resembling that of the atmosphere, and respirable as that is\*.

5thly. It is now a well established fact, that the *azote*, or basis of phlogisticated air, is literally the basis of the nitrous acid†; for being mixed in proper proportions with oxygen or pure air, which is

\* Briffon, tom. ii. p. 35.

† It is almost unnecessary to inform the reader, that nitrous acid is that substance commonly sold in the shops under the name of *aqua fortis*. It may seem surprising to be told, that the air which we are commonly breathing is essentially *aqua fortis*—But though that extremely corrosive and deadly fluid is really composed of azote and oxygen, yet they are then in a state of *combination*, whereas in atmospheric air they are only *mixed*.

necessary to give to these bases the acid character, and set on fire by passing through them an electric spark, nitrous acid is uniformly produced, as is evident from the experiments of Mr. Cavendish.

6thly. Late discoveries have also evinced, that the volatile alkali is formed from a union of this gas with hydrogen, or inflammable air.

The further uses and properties of this air will be better explained when I come to treat of the atmosphere.

## CHAP. IV.

FIXED OR FIXABLE \* AIR, OR CARBONIC  
ACID GAS.

*The Basis of this Air is the elementary Matter of Charcoal.—Combined with Oxygen.—Modes of producing it.—Fermentation.—Quantity contained in different Kinds of Wines.—Choak Damp.—Properties of Fixed Air.—Great specific Gravity.—May be poured out of a Vessel like Water.—Resists Putrefaction.*

**I**N enumerating the principles of bodies †, it will be recollected, that coal, or *carbon* (according to the French chemists) was considered as a simple elementary substance. Carbonic acid gas, however, is by no means entitled to this character. It receives the name of *carbonic*, because its actual basis is the matter of coal, or, more properly, charcoal. It is called *acid*, because a quantity of oxygen enters into its composition. It is denominated a *gas*, from the matter of fire which gives it the character of a permanently elastic or aeriform fluid. The proportion of the materials which enter into this kind of air is about eighteen parts of oxygen and seven

\* So called at first from its supposed quality of existing in a fixed state in certain bodies, as in lime, chalk, &c.

† Book I. chap. 2.

parts of that matter which the French philosophers denominate carbon, or coal.

If, for example, charcoal is burnt in a close vessel with oxygen gas, the air which remains after combustion is this carbonic acid gas. By the experiments of Lavoisier and De la Placé it appeared, that one ounce of charcoal required for its combustion three ounces and one third of vital air, and produced three ounces and an half of fixable air.

There are several methods of procuring fixed or fixable air, or carbonic acid gas; first, by the fermentation of liquors, in which operation its formation is owing to the combination of the carbon of the saccharine matter with the oxygen of the water.

It is evident that a great quantity of fixed air is produced, when vegetable or animal substances (especially the former) are in a state of vinous fermentation. In breweries there is always a stratum of fixed air on the surface of the fermenting liquor, reaching as high as the edge of the vats; and it is owing to the production and elasticity of fixed air, that fermenting liquors, when put into close vessels, often are known to burst them with great violence.

Dr Priestley, in order to determine the quantity of fixed air contained in several species of wine, took a glass phial (fitted with a ground stopple and tube) capable of containing an ounce and half measure. This he filled with wine, plunging it into a vessel of water. The whole was then put over a fire, and the water in which the phial was plunged suffered to  
boil,

boil. The end of the tube in the stopple being placed under the mouth of an inverted receiver filled with quicksilver, the heat expelled the fixed air from the wine, which, entering into the receiver, ascended in bubbles through the quicksilver to the top, removing in its passage a part of the metal, and assuming its place in the receiver. The result of the Doctor's experiment may be interesting to some readers, and to others it may at least afford entertainment.

1  $\frac{1}{2}$  oz. of Madeira produced  $\frac{1}{100}$  of an oz. meas. of fixed air.

Port 6 years old -  $\frac{1}{48}$

Hock of 5 years -  $\frac{1}{24}$

Barrelled claret -  $\frac{1}{12}$

Tockay of 16 years  $\frac{1}{18}$

Champagne of 2 years - 2 oz. measures.

Bottled Cyder of 12 years  $3\frac{1}{4}$

Fixed air may be easily obtained by mixing together equal parts of brown sugar and good yeast of beer, and adding about twice the quantity of water. This mixture being put into a phial, to which a bent tube with a cork or stopple may be adapted, will immediately ferment, and yield a considerable quantity of fixed air, which may be received into a phial filled with quicksilver or water.

2dly. Fixed air is produced by the respiration of animals ; in which case the oxygen of the air inspired furnishes part of its heat to the support of life, and combines with the carbonaceous or coaly

matter, which is disengaged from the blood in the lungs.

3dly. From what has been previously stated it is evident, that fixed air may be produced by the combustion of any carbonaceous or coally matter.

4thly. Fixed air is also extricated in large quantities by the action of acids on calcareous earth.

Fill a phial or a glass receiver with water, and invert it (in the same manner as described in the chapter on dephlogisticated air) in a basin half filled with water. Then put some chalk or marble grossly powdered into another bottle, so as to fill about a fourth or fifth part of it, and pour water upon it until the chalk is covered, then add some vitriolic acid to it, in quantity about the fourth or fifth part of the water, and apply a cork with a tube as before to the bottle, so that the extremity of the tube may pass through the water of the basin into the neck of the other bottle which is inverted in the water. The mixture of chalk and oil of vitriol will then begin to effervesce, and heat is produced, which may be felt by applying the hand to the outside of the vessel. Fixed air is copiously emitted from this mixture, and, passing through the bent tube, will proceed into the bottle inverted in the water, and ascend to the top of it. By these means the inverted bottle may be filled with fixed air, and being corked under water, may be removed from the basin, and kept for use.

5thly. Fixed air is also expelled in large quantities, by the application of heat only, from lime,  
chalk,



chalk, magnesia, or alkaline bodies, in what is called their mild state, opposed to caustic; and by the experiments of Dr. Black it was found, that this substance constituted nearly one-third of the weight of those bodies. The alkalies and calcareous earths have consequently a very powerful attraction for this fluid in their caustic state; and it is therefore easily condensed by agitation with lime water, as has been already intimated.

This gas was long known to miners by the name of choak damp, so called from its fatal suffocating effects; and its properties may be enumerated in few words. 1st. It extinguishes flame. 2d. It is fatal to animal life. 3d. It is heavier than common air. 4th. From its acid character it resists putrefaction. 5th. It renders alkalies, &c. mild. 6th. Water, under the common pressure of the atmosphere, and at a low temperature, absorbs somewhat more than its bulk of this gas, and in that state constitutes a weak acid rather agreeable to the taste, whence fixed air is a constituent principle in most mineral waters; indeed the water of springs and rivers is seldom free from it. 7th. It is also a constituent principle of all fermented liquors.

If a lighted wax taper is let down into a bottle filled with fixed air, the flame will be instantly extinguished, and an animal inclosed in a vessel which contains it will immediately expire.

This fixed air will be found to be much heavier than common air; its specific gravity being to that of common air as 151 is to 100.

From

From the greater weight of this gas it always falls to the bottom of the vessel in which it is contained. An animal introduced into a stratum of this air immediately expires; and it is owing to the presence of this fluid that the Grotto del Cani in Italy is fatal to animals whose organs of respiration are placed below the level of the mouth of that cavern. This gas may be poured out of one vessel into another like water, or may be poured on a candle, which it will extinguish as effectually as that fluid.

Among the most useful properties of fixed air, it has been remarked, that water impregnated with it becomes a powerful antiseptic. Most of the famous mineral waters may be imitated by impregnating water with fixed air, and then adding that quantity of salt or metal, chiefly iron, which those mineral waters, by analysis, are known to contain. It is from this property of preventing putrefaction, that fixed air, and vegetables, sugar, and other substances, which abound with that principle, are supposed to be powerful remedies in putrid diseases.

Fixable air not only preserves fruit, but meat also, from putrefaction, and that for a very considerable time, and even in the hottest weather.

## C H A P. V.

INFLAMMABLE AIR OR HYDROGEN  
GAS\*.

*This Gas forms the Basis of Water.—Proportion of Hydrogen and Oxygen which enter into the Composition of Water.—Modes of procuring inflammable Air.—Ignes Fatui.—Fire Damp in Mines.—Lightest of all Fluids.—Remarkable Properties.—Use in Air Balloons.—Curious aerial Fire Works.*

**T**O that fluid, which we term inflammable air, the French chemists have given the name of hydrogen gas, because its basis is the peculiar constituent part of water; but what this basis may be in its nature, whether simple or compound, is at present unknown, because it cannot be separated from the heat or caloric which gives it the aerial form, without fixing it in another substance.

According to M. Lavoisier, water is composed of eighty-five parts of oxygen and fifteen parts of hydrogen. This philosopher has instructed us in the following method of obtaining this gas by heat only †.

Let water pass drop by drop through the barrel of a gun, while it remains red hot amidst burn-

\* ὕδωρ (hydor) “water” and γεινομαι (geinomai) “to produce.”

† Brissot, tom. ii. p. 73.

ing coals; let a crooked tube placed at the end of this iron, and bent so that it may be passed into a glass vessel full of water inverted in the pneumatic apparatus. There will then pass into the glass vessel an aeriform fluid, which is inflammable air or hydrogen gas. In this process the water suffers a decomposition, and while the hydrogen passes into the glass receiver, the oxygen unites with the substance of the gun barrel, and oxydates or rusts its internal surface.

By means of acids, however, inflammable air may be obtained in greater abundance, and with more facility. When iron, zinc, or tin, are acted upon by diluted vitriolic, or marine acid, considerable quantities of this gas are extricated. In this case also the water is decomposed, as is plain from the concentrated vitriolic acid not answering the same ends as the diluted, either in furnishing the air or dissolving the iron, &c.

The apparatus for procuring this gas is the same as that which has been described for producing fixed air, only employing, instead of chalk, iron filings, small nails, small pieces of iron-wire, or grossly powdered zinc. To these materials some oil of vitriol and water must be added in the same proportion as in the process for producing fixed air.

The electric spark, taken in any species of oil, produces hydrogen or inflammable air, this substance being a constituent part of all the oils. The same may be said of ether, and alcohol or spirits of wine, which contain a great proportion of hydrogen.

Mr.

Mr. Cavallo informs us, that he has procured this kind of air from the ponds about London, in the following manner. Fill a wide mouthed bottle with pond-water, and keep it inverted in it; then with a stick stir the mud at the bottom of the pond just under the inverted bottle, so as to permit the bubbles of air which rise to be received in the inverted bottle; and this air will be found to be inflammable.

The ignes fatui are supposed to proceed from the inflammable air which abounds in marshy grounds, and to be set on fire by electric sparks.

This gas, as well as fixed air, was long known to miners before it was noticed by philosophers; and among the colliers and other workmen of that class, it obtained the name of the fire damp. It is however seldom found pure in mines or coal works, but is generally combined with sulphureous matter, or what is called hepatic gas, or with carbonic acid air; and this admixture varies its specific gravity, and in general renders it something heavier than pure inflammable air. The fire damp generally forms a whitish cloud in the upper part of the mine, and appears in something of a globular form; from its levity it will not mix with the atmospheric air, unless some agitation takes place; and it is disposed to lodge in any little cavity in the superior part or roof of the mine. When it appears in this form, the miners generally set fire to it with a candle, lying at the same time flat on their faces to escape the violence of the shock. It will not, however, take fire

fire unless in contact with atmospheric air, for the obvious reason, that a mixture of oxygen gas is necessary to its inflammation. The danger arises entirely from its inflammability on the approach of any ignited body, for when the fire damp consists of pure inflammable air, the explosion is like that of gunpowder; but when it is mixed with carbonic acid, it burns with a lambent flame. The easiest and safest method, therefore, of clearing the mine from this formidable fluid is by leading a long pipe through the shaft of the mine to the ash-pit of a furnace, when the inflammable vapour will be constantly attracted to feed the fire.

Dr. Priestley has sufficiently proved by experiments, that there is no acid contained in inflammable air. He also asserts that charcoal, by the heat of a burning lens, may be almost totally converted into this kind of air, but that some moisture is necessary in the process. The necessity of moisture, however, to the success of this experiment, sufficiently evinces the fallacy of the conclusion which has been drawn from it. Perfectly pure charcoal, abstracted from every other body, is indestructible by heat. Where, however, there is moisture there is water. In this case the oxygen of the water is attracted by the carbon, forming with it carbonic acid, and the hydrogen, the other constituent part of water, rises to the top of the receiver. Pure hydrogen gas is the lightest of all elastic fluids, its specific gravity is to that of common air as 8,04 is to 100,00\*.

\* Brissou, tom. ii. p. 77.

The most remarkable properties of this gas are,  
1st, its great inflammability, which arises from its propensity to unite with oxygen and form water.  
2dly. Its extraordinary levity, as already noticed.  
3dly. Metals are very easily revived or reduced from a calx or oxyd to the metallic state when heated in a receiver filled with this air. This also arises from its attraction for oxygen, which in this case is expelled from the calx, and, uniting with the hydrogen in the receiver, leaves the metal pure, and in its natural state. 4thly. Plants vegetate in this fluid without impairing its inflammability. 5thly. Water will imbibe about one-thirteenth of its bulk of this gas, which may be again expelled by heat, and will then be equally inflammable as before. 6thly. Hydrogen gas, or inflammable air, is fatal to animal life; in proof of which Mr. Cavallo relates, that the Abbe Fontana, having filled in his presence a large bladder with inflammable air, began to breathe it, after having made a violent expiration. The first inspiration produced a painful oppression on his lungs; the second caused him to look pale; and the third was scarcely accomplished, when he fell on his knees through weakness. Small animals are also killed by a very few inspirations of this noxious fluid. 7thly, This gas is said to have a smaller share of refractive power than common air.

It is on account of its lightness that hydrogen gas has been most frequently employed in aërostation. The method of filling a balloon is only enlarging the process which has been described for producing inflammable air on a small scale.

Very

Very pleasing fireworks may be made from this gas, by filling bladders with it, and fixing brass cocks to them, by means of which the gas may be dispersed into any number of glass tubes bent in various shapes, and with small holes in various parts of them; then by pressing the bladders more or less, as occasion may require, the gas will pass into the tubes, and issue out of the small holes, to which a lighted taper may be applied; by these means the air will take fire, and will continue to burn until the course of it is stopped by shutting the cock at the neck of the bladder. These aerial fireworks may be made to represent different figures, either moveable or immovable, and may be ornamented with different colours. The white coloured flame is produced by hydrogen gas procured from common coal; again, by mixing an equal quantity of this air with atmospheric air, a flame of a blue colour will be produced; the pure hydrogen from metals furnishes a red flame; and if by breathing, some carbonic acid gas or fixable air is added, the flame will appear beautifully tinged with purple\*.

\* See Briffon, tom. ii. p. 81.



## NITROUS AIR OR GAS.

**N**ITROUS gas ought properly to be considered as an intermediate state of that elementary substance which is the basis both of azotic gas and nitrous acid. Azote, perfectly saturated with oxygen, forms pale nitrous acid; with a smaller portion, it constitutes the ordinary orange-coloured and fuming nitrous acid; with still less, it becomes nitrous gas; and when wholly uncombined with oxygen, is denominated azotic gas. In the state of azotic gas it is insoluble; but in proportion to the quantity of oxygen with which it is combined, its disposition to assume an aeriform state is diminished, and its attraction for water increased.

In order to produce nitrous air, put copper, brass, or mercury, first into the bottle (with the same apparatus as for the other airs) so as to fill about one third of it, then pour a quantity of water into it, so as just to cover the metal filings; and, lastly, add the nitrous acid, in quantity about one half or one third,

third, according to the strength which is required. Nitrous air contains, in 100 grains, 68 of oxygen, and 32 of azote.

On its relation to the nitrous acid the distinguishing properties of this gas will be found to depend.

1st. Nitrous air is as invisible and transparent as common air; in its smell it resembles nitrous acid. Though this kind of air extinguishes flame, it may, by certain processes, be brought to such a state, that a candle will burn in it with an enlarged flame, and it then becomes what Dr. Priestley calls *dephlogisticated nitrous air*. Its supporting flame in this instance evidently depends on the large quantity of oxygen which enters into its composition.

2d. When oxygen or empyreal air is added to nitrous air, it imparts to it the acid character, and it becomes true nitrous acid. Mr. Cavendish impregnated fifty ounces of distilled water with fifty-two ounce measures of nitrous air, mixed with as much common air as was necessary to decompose it. The water thus impregnated was sensibly acid, and being distilled, the first runnings were very acid, and smelt pungent: what came next had no taste or smell; but the last runnings were very weak nitrous acid\*.

3d. Of all the different species of air, this seems the most noxious to animal life. Insects, which can bear azotic and inflammable air, will die imme-

\* Phil. Trans. for 1784.

diately upon their being immersed in this. Even fishes will not live in water impregnated with it.

It may seem extraordinary that nitrous gas, which is of so deleterious a nature, and so opposite in its qualities to common air, should yet substantially consist of the same principles, differing, however, in the proportions. To remove the difficulty, it will be necessary to recollect what has been more than once intimated concerning the difference between *mixture* and *combination*. In simple mixture the two bodies still retain their own distinct properties; but in chemical combination a third substance is formed from the two, entirely different from both in its nature and properties. Thus, from marine acid or spirit of salt, and caustic alkali, both extremely corrosive, is formed that innocent and wholesome substance, common salt; and from two substances innoxious to the human frame, sulphur and oxygen, vitriolic acid, or spirit of vitriol, is formed. In common air, azote and oxygen are indeed in a state of mixture, but they are not combined; for to make them enter into a state of combination, the operation of a strong agent, such as fire from the electric spark, is necessary, and without this, azote appears to have little or no attraction for oxygen. In the ordinary process of respiration the mixed substances are inhaled; and it is probable that they are soon again separated in this process, and each differently disposed of. In nitrous gas, the azote and oxygen are in a state of chemical combination, and it is a third substance different in qualities from both; it is,

indeed, an imperfect nitrous acid in an aerial form; though azote, therefore, in its simple uncombined state, has no attraction for oxygen, it is different when by combination it becomes an acid; it has then a strong attraction for that substance which is necessary to give it the true acid character, and it will absorb it till it arrives at what the chemists call the point of saturation, that is, till it is made a perfect acid; and this is the reason that it so rapidly attracts and condenses the pure part of the atmosphere.

4th. Nitrous air possesses the property of preserving animal substances from putrefaction, and of restoring those already putrid, in a still greater degree than fixed air, and on this the antiseptic power of nitre may, perhaps, chiefly depend. On putting two mice, the one just killed, the other putrid and soft, into a jar of nitrous air, and letting them continue in it twenty-five days, in the months of July and August, there was little or no change in the quantity of air; both mice were perfectly sweet; the first quite firm, the flesh of the second still soft, but not in the least putrid. From these experiments Dr. Priestley recommends nitrous air as an antiseptic. Unfortunately, however, though animal substances may be preserved from putrefaction for several months by nitrous gas, yet they become dry, distorted, and offensive to the palate, so as to render the discovery of little public utility.

5th. The specific gravity of nitrous air is to that of the atmosphere as 1195 to 1000.

6th. One

6th. One of the most remarkable properties of this air is, that it condenses or diminishes in bulk with oxygen or dephlogisticated air, by which means it becomes a test with respect to the quantity of that pure element contained in the atmosphere. With pure dephlogisticated air the diminution is almost to nothing, at the same time that nitrous acid in some quantity is reproduced by the decomposition of the nitrous air; but as our atmosphere is always mixed with a considerable quantity of azotic or phlogisticated air, on which nitrous air has no effect, the diminution in this case is never so considerable. Upon this principle the eudiometer for measuring the purity of air is formed.

To understand the nature of this instrument, let a glass tube (Fig. 4.) of about nine inches long, closed at one end, and of about three-fourths of an inch diameter, be filled with and inverted in water; then take a phial of about half an ounce measure, filled with common air, and plunging it under the water contained in the same basin with the inverted tube, let that quantity of air enter into the tube; it will then rise to the top of the tube while the water subsides. Let a mark be made on the tube at the height of the water in it, to show how much of the tube is filled by that measure of air. In the same manner inject four or five measures of common air, marking the height of the water at every one respectively. After this process, if three measures of either nitrous or common air are introduced into the tube, they will cause the water to subside to the

third mark ; but if two measures of common air and one measure of nitrous air, or one measure of the common and two of the nitrous air, are put into the tube, they will fill a space much short of the third mark. When these two kinds of air come first in contact, a reddish appearance is perceived, which soon vanishes, and the water, which at first nearly reached the third mark, rises gradually into the tube, and becomes nearly stationary after about two or three minutes, by which it appears, that the diminution takes place gradually.

Nitrous air is neither soluble in water nor possesses any signs of acidity ; for it has not the power of changing the blue colour of vegetables red, unless it is mixed with common or dephlogisticated air, by which it acquires the true acid character \*.

\* Briffon, tom. ii. p. 39.

## C H A P. VII.

## OF HEPATIC GAS.

*Nature of this Gas.—Means of producing it.—Its Properties.—A chief Constituent of Sulphureous Mineral Waters.—Turns Metals Black.—How decomposed, &c.*

**M.** Gengembre, who has made an analysis of this kind of air, regards it as proceeding from pure hydrogen and sulphur. The most proper method of obtaining this air is by pouring marine acid on liver of sulphur\*, which extricates it in considerable quantities. It is equally produced from all livers of sulphur, whether they are made with alkalis or earths. By various experiments, however, it now seems to be ascertained, that as hepatic gas is composed of sulphur and hydrogen in certain proportions, it cannot be produced except water is present, the decomposition of which affords the hydrogen. Thus, if marine acid air is applied to very dry liver of sulphur, scarcely any hepatic gas is produced, from the defect of humidity. Liver of

\* A substance usually formed from fixed alkali, or salt of tartar, and sulphur combined by heat.

fulphur, when heated, affords hepatic gas with the addition of mere water without acid. In this case also the water is decomposed; its hydrogen unites with part of the sulphur to form hepatic gas, while the oxygen of the water uniting with another part, produces vitriolic acid, and this with the alkali forms a neutral salt which may be easily obtained.

1st. Hepatic gas is very soluble in water, which it converts into a state perfectly resembling that of sulphureous mineral waters. 2d. It detonates with vital air when set on fire. 3d. It is not clearly ascertained in what manner sulphur is suspended in hepatic gas. Sulphur melted by a burning glass, in inflammable air over mercury, produces a fluid which has the properties of hepatic gas; and if inflammable air is passed through sulphur in fusion it is converted into hepatic gas. 4th. The smell of this air is very unpleasant, and its vapour has a very disagreeable effect, upon many metallic substances, particularly silver, lead, copper, &c. destroying their colour, and rendering them almost black. 5th. It is extremely pernicious in respiration. 6th. It may be decomposed by vitriolic and nitrous air, by vital air, and by the contact of atmospheric air, in which case it deposits some sulphur. Its great attraction for some of the metals and their calces makes it the basis of some sympathetic inks.

The volatile alkali, and most of the acids, may be made to assume an aerial form, and have been distinguished



distinguished under the appellation of alkaline and acid airs; it is unnecessary, however, to introduce the subject in this place, and it will be better understood when the acids and alkalies are treated of, as they will be in the succeeding book,

## C H A P. VIII.

## OF ATMOSPHERIC AIR.

*Atmosphere composed chiefly of Two Kinds of Air.—Contains also Fixed Air, and occasionally other Substances.—Effects of this Mixture on Metals and Purple Dyes.—Means of purifying the Atmosphere from Fixed Air, and putrid Vapours.—Effects of Moisture contained in Air.—The Hydrometer.—Cold in the higher Regions of the Atmosphere.—Cause.*

**W**HATEVER has been hitherto stated relative to the different species of elastic fluids is chiefly important, because the knowledge of these fluids is necessary to enable us to comprehend the nature of that atmosphere in which we exist, and which is indeed of itself one of the principal agents of our existence.

In treating separately of the different kinds of air, it was necessary in some measure to anticipate the present subject, and to intimate that the air of our atmosphere is not, as was formerly supposed, a simple homogeneous fluid, but that in reality it is composed of two different fluids, which have been described under the appellations of azotic and oxygen gas, or phlogisticated and vital air.

In one hundred parts of atmospheric air there are contained about seventy-two parts of azotic gas  
to

to twenty-seven of oxygen, besides one part of carbonic acid gas or fixed air, which is generally found united with them, or to speak in round numbers, in order to be better understood, we may say that the air of our atmosphere contains rather better than one fourth of pure or respirable air, and that the remaining three fourths are unfit for respiration, and equally unfit for combustion, since the same fluid which supports flame is found equally to contribute to the support of animal life.

By the combustion of any inflammable substance in a close vessel filled with atmospheric air, it will be found that about a fourth part of the whole bulk of the air will disappear, and that the combustion will gradually cease in proportion as that fluid is diminished which is necessary to its support.

The same quantity is destroyed by the process of respiration. Putrefaction also separates the pure air; and the power of separating, and also of reuniting the two fluids, which last may be done, when both are produced by artificial means, very sufficiently proves them distinct in their nature and properties, and also that they are united in the air of our atmosphere.

Azotic gas being specifically lighter than oxygen, it might naturally be supposed, that since they only exist in the atmosphere in a mixed state, and not in a state of chemical combination, a spontaneous separation would take place, and that the azote would occupy the higher regions of the atmosphere, whereas

412 *More Vital Air in Summer than Winter.* [Book V.

whereas it is found by experiments with the eudiometer, that the upper regions of the air actually contain a greater proportion of oxygen than those nearer the surface of the earth. Whether this is to be attributed to the attraction which azote may have for the earth, or to some unknown property in the oxygen, we cannot now determine, and can only take the fact as it stands, without attempting its explanation \*.

From the great consumption of oxygen by various natural and artificial processes, it might be expected that a deficiency of this fluid in the atmosphere might sometimes occur; but the wisdom of Providence is evident in this, as well as in every other instance; for we have already seen that the processes in nature which destroy this air are nearly balanced by those which produce it. A series of experiments were made at Stockholm by the indefatigable Scheele, to ascertain the goodness of the air during every day in the course of a year. He found that the diminution by the eudiometer never exceeded one-third, nor was less than eight thirty-thirds. The quantity of vital air was least in March, November, and December, and in general less in the winter than in the summer months, which may be attributed to the redundant supply of this matter by the copious vegetation which takes place at that period. The air

\* A mixture of empyreal and inflammable airs remaining all night, was found the next morning in the most perfect state of mixture, and the electric spark passed through them with the usual effect. *Priestley's Experiments.* Vol. vi. p. 27.

at sea is generally found in a purer state than at inland places.

Extraordinary as this mixture of fluids in the atmosphere may appear, it is essential to our health, and even our existence, and demonstrates no less the wisdom and goodness of Providence, than all his other beneficial appointments. This pure vital air, says Briffon, so wholesome, so necessary in a moderate quantity; like spirituous liquors, or salutary medicines, must be used with precaution, and would be fatal in the excess. If we were indeed to breath pure or oxygen air without any mixture or alloy, we should infallibly perish by the unnatural and fatal accumulation of heat in our bodies; if, again, the whole atmosphere was composed only of vital air, combustion would not proceed in that gradual and moderate manner which is necessary to the purposes of life and of society; and even iron, and the metals themselves, would blaze with a rapidity which would carry destruction through the whole expanse of nature.

The air of our atmosphere is, however, not so simple a substance as to be formed only of two ingredients. Besides the small portion of carbonic gas or fixed air which it contains, equal to one hundredth part, as was intimated in the beginning of this chapter, it is also well known that a large portion of water is usually held in the atmosphere, sometimes in a state of perfect solution, or entirely invisible, and sometimes visible in the form of mists and clouds. The atmosphere is also the general recipient

414 *How Air is commonly contaminated.* [Book V.

recipient of all those substances which are subject to evaporation, and which preserve their aeriform state under its ordinary heat and pressure.

From the mixed nature of the mass, and particularly from the mixture of carbonic acid gas or fixed air, several effects are produced, and some of them it may be proper to notice. Fixed air being in reality an imperfect acid, contributes to rust metals, and to change the colour of such purple dyes as are produced from vegetable substances. This is an effect which most persons have noticed, though the cause has not been understood; and the delicate nature of these colours has been almost an invariable objection against their use.

The air of the atmosphere is most generally injured by the destruction of the pure part, and the generation of carbonic acid gas, as in most of the processes of combustion, and in that of respiration. When it is necessary to purify the air from the carbonic acid, which may be too abundant in it, any contrivance for bringing it into contact with lime-water will sufficiently answer this purpose. A cloth dipped in that liquor, and suspended near the floor, will generally purify the air of a room from any contamination of fixed air.

Combustion or respiration are, however, not the only means by which atmospheric air is injured. Phosphorus of every kind, liver of sulphur, oil of turpentine, cements of wax, oils of mint, cinnamon, &c. nitrous acid, and even nitrous æther, at once diminish and deprave it.

The air is also rendered unwholesome by the absorption of putrid\* or inflammable vapours, the explosion of gunpowder, by oil paints, by the volatile spirit of sal ammoniac, by spirits of wine, by every kind of perfumery or artificial scents, by the vapour of new plaistered walls, by all putrid substances, and especially by stagnate water; these substances all diffuse a quantity of inflammable air or vapour through the surrounding atmosphere, and some of them consume the pure or vital part. Even the vapour of pure water in considerable quantities is pernicious to animal life; Muschenbroek observed, that it threw a bird into great anxiety; that the vapour of vinegar had a similar effect; that the vapour of spirit of wine killed a bird; and that several others were fatal to life †.

From these facts it is manifest that the burying of the dead in populous towns is a wretched and dangerous mockery of police. I know a certain great town where, in burial places in the very middle of the town, the dead are buried not six inches below the surface; and in London, notwithstanding the act of parliament, what with the present evasion of

\* A quantity of corrupted fish were once thought to have occasioned a violent epidemic fever at Venice. The same effect was produced at Delft, by the corruption of vegetables. The Arabs, when desirous of injuring the Turks at Bassora, break down the banks of the river near that city, so as to permit it to overflow a great tract of land; a violent fever is generally the consequence of the putrid mud, &c. which is left behind after the water is evaporated.—*Cav. on Air*, 457.

† Cavallo on Air, p. 447.

that

that act, the depositing in vaults, and the frequent breaking up of the ground, and removing putrid bodies, the case is not much better; and indeed much might yet be done to render the air of London more salubrious than it is.

I have taken no notice of the accounts which some ingenious men have afforded us of the salubrity of the air in different places, convinced that we are not as yet possessed of a complete test of the salubrity of air; and till this can be procured our only guide must be experience.

By agitating putrid and inflammable air in distilled water, or water from which the air has been expelled by boiling, a considerable diminution will take place, sometimes above a third of the bulk, and the air will be considerably purified. Thus the agitation of the sea, and of large lakes, has probably the happiest effect in purifying the atmosphere.

Dr. Hales found that air might be breathed much longer, when in the act of respiration it was made to pass through several folds of cloth dipped in vinegar, a solution of sea salt, or oil of tartar, than when no such contrivance was used; the reason of which is briefly, that these substances absorb the fixable air which comes from the lungs\*.

Putrid air was also restored by a mixture of carbonic acid air. The experiment was, however, in some measure rendered doubtful by the air having been passed through a vessel of water in order to its admixture. If, however, the fact is well found-

\* Hale's Ess. p. 266.



ed; lime kilns in the vicinity of populous cities may possibly not be so unwholesome as is generally imagined, as in those places the putrid air and vapours abound more than the carbonic acid.

The eudiometer is a good test of air as far as regards the diminution of the oxygenous part; but it is on the whole an imperfect instrument, as it affords no means of distinguishing the deleterious vapours with which the atmosphere may occasionally be charged.

Besides their deleterious properties, the mixture of watery particles and vapour in air has also considerable effect with respect to its power of conducting heat from our bodies. The rarity or density of air seems to have little effect with respect to its conducting power, which indeed appears entirely to depend on the quantity of moisture it contains. A moist air conducts heat with much greater rapidity than a dry air. Whence (says the ingenious Count Rumford) ‘ I cannot help observing with what infinite wisdom and goodness, Divine Providence appears to have guarded us against the evil effects of excessive heat and cold in the atmosphere; for were it possible for the air to be equally damp during the severe cold of the winter months, as it sometimes is in summer, its conducting power, and consequently its apparent coldness, when applied to our bodies, would be so much increased by such an additional degree of moisture, that it would become quite intolerable; but, happily for us, its power to hold water in solution is diminished, and

with it its power to rob us of our animal heat, in proportion as its coldness is increased. Every body knows how very disagreeable a very moderate degree of cold is when it is very damp; and hence it appears, why the thermometer is not always a just measure of the apparent or sensible heat of the atmosphere. If colds or catarrhs are occasioned by our bodies being robbed of our animal heat, the reason is plain why those disorders prevail most during the cold autumnal rains, and upon the breaking up of frost in the spring. It is likewise plain, whence it is that sleeping in damp beds and inhabiting damp houses is so very dangerous, and why the evening air is so pernicious in summer and autumn, and why it is not so in the hard frosts of winter. It has puzzled many to account for the manner in which such an extraordinary degree, or rather quantity, of heat is generated, which an animal body is supposed to lose if exposed to the cold of winter, which it communicates to the surrounding atmosphere in warm summer weather; but is it not more than probable, that the difference of the quantities of heat actually lost or consumed, is infinitely less than what they have imagined \*?

Various instruments have been invented under the general name of hygrometers †, for ascertaining the quantity of moisture contained in the at-

\* Thompson's Experiments. Phil. Transf. Vol. lxxvi.

† 'Υγρος, (hygros) "moisture;" and Μέτρον, (metron) "measure."

mosphere.

mosphere. Most bodies attract moisture, and are expanded by it. Wood and other solid bodies are swelled by the moisture insinuating itself between the fibres, and consequently a piece of wood cut transversely, will be extended in length by the absorption of damp or wet. Cord, catgut, &c. the fibres of which extend longitudinally, will increase in thickness, but will contract in length on the application of moisture. On this last principle the common weather-house is constructed, which is no bad hygrometer for general purposes; the contraction of the string by wet forces the man out of the door, and when by the return of fine weather the string or catgut is disposed to resume its natural length, an elastic wire acts upon it, and the woman appears. The first regular and graduated hygrometer that deserves to be mentioned, as made in this country, was that of the late ingenious Mr. Smeaton. He employed in its construction a flaxen string of three threads, commonly used in making nets, which, in order to make it attract the moisture readily, he steeped in salt and water. This he extended along a board properly graduated, and to one part contrived to attach an index, which served to shew its variations. M. Saussure employed a hair for the same purpose, which he suspended by a weight of three grains, and contrived it to act upon an index pointing to a graduated scale; and this was found to be a very delicate and accurate instrument.

M. de Luc, however, conceived that a solid

body would afford the most accurate and steady measure of damp or dryness, and was less likely to be out of order than fibrous and twisted substances. He successively employed ivory, boxwood, and whalebone; but after several trials preferred the latter, because of its great power of expansion, which sometimes exceeded one-eighth of its length, and because of its steadiness, in always coming to the same point in extreme moisture. His hygrometer therefore consists of a very thin slip of whalebone, about 12 inches in length, and a line in breadth, cut transversely to the direction of the fibres. This he extends by a small spring, and the variations may be either measured by a mark on the whalebone or by an index. This is at present the most perfect hygrometer, and that which is in most general use.

In the higher regions of the atmosphere the cold is found to be intense, and yet the moisture is generally said to be less abundant, than in those nearer the surface of the earth. This was experienced by all the adventurers in air balloons, as well as by those travellers who have ascended to the tops of high mountains. It is well known that the summits of the alps and other great elevations are usually covered with snow. There is indeed always a certain height of the atmosphere where water will be found at the freezing point, and this has been called by philosophers the line of perpetual snow. The line, however, varies according to climate and circumstances. On the peak of Tenerif it commences at  
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the height of about two miles and a half, and in England it is generally found at the height of a mile, or a mile and a half. Some botanists have asserted, that the variation of climate in ascending mountains, was discernible from the vegetables found upon them, the plants which required a mild temperature, being commonly found near the bottoms, and the hardier, and more northern vegetables towards the summit.

Different opinions have been entertained concerning the cold in elevated situations. It was for a considerable time imagined, that it depended altogether on the rarity of the atmosphere in those regions, which is very considerable; but it has been remarked, on the authority of Count Rumford, that the rarity or density of the air appears to have little effect on its conducting power. Some have supposed, that as the air is so much rarer in the upper regions, less fire or caloric is required to keep it in a state of fluidity, and consequently that there is a real deficiency of that element. The hypothesis of M. Bouguer\*, however, comes recommended by its simplicity, and by its agreement with most of the other phenomena of heat, and I shall therefore adopt it with only some slight variations.

Without entering into the controversy concerning the identity of fire and light, it is only necessary to assume as a principle the well known circum-

\* Reasons for the cold on the top of the Andes.

stance, that the action of light is capable of producing heat in bodies; and the equally well established fact, that the action of light upon a transparent medium, through which it is easily transmitted, is extremely feeble. This may be proved by the easiest of all possible experiments. If highly rectified spirits are inclosed in a pure glass phial, or any perfectly transparent vessel, the rays of light concentrated by the most powerful burning glass, will not inflame them; if, however, the spirits are placed in a spoon, or if that part of the transparent vessel which is not opposed to the burning glass, is coated with paint or any substance, which intercepts the rays of light, imbibes or condenses them, the spirits will be instantly set in a blaze. The earth is therefore the great receptacle of heat, where it is absorbed and kept as in a store-house; but the surface of earth which is exposed to the sun on the tops of mountains is but very small, and cannot imbibe much of the sun's heat. The rays from the sun can indeed only strike the different sides of the mountain for a short period in every day, and in some days, and in some parts, not at all. "A horizontal plain also when the day is clear, is exposed at mid-day to the perpendicular and undiminished action of the sun's rays, while they fall obliquely on a plain which is much inclined, or on a pile of rocks." In these elevated situations, therefore, the majority of the sun's rays pass through a transparent medium, as through the spirits inclosed in a clear glass vessel; and there is no mass of

opaque matter to collect or condense the heat. The atmosphere, therefore, in those regions is necessarily colder than in those which approach nearer the surface of the earth.

The cold in these higher regions of the atmosphere, may be one cause why vapours are not collected so plentifully there as nearer the earth. The clouds are seldom more than a mile in height, and they do not often attain that degree of elevation. From the summit of a high mountain, therefore, the prospect is inexpressibly grand. The clouds roll beneath the spectator's feet like the vast waves of a troubled ocean; and the forked lightnings play between those immense masses in various directions; while the great body of air in the vallies beneath (clear and transparent as it appears to those who inhale it, but in reality charged with vapours) appears like the water of a stagnant lake, involving most of the objects in total darkness, and partially revealing others, which seem as if intended to adorn the margin of the flood, and serve to enliven and diversify the scene.

## C H A P. IX.

OF THE WEIGHT, ELASTICITY, AND  
OTHER GENERAL PROPERTIES OF  
THE AIR

*General Properties of Air.—Cause of its Elasticity.—Opinions of the Ancients.—Torricellian Experiments.—Barometer.—The Air Pump.—Weight and specific Gravity of Air.—Immense Pressure of the Atmosphere.—Compressibility of Air.—Cupping Glasses.—Effects of the Air's Elasticity.—Air Guns, &c.—Motion of Particles in Bodies.—Nature of the Atmosphere.—Its probable Height.*

**T**HE air, considered as a fluid, without any respect to its component principles, has also some properties which are of the utmost importance in the system of nature; and the consideration of these properties will serve to illustrate and explain the nature of all other elastic fluids.

Atmospheric air, considered in itself, is a ponderous, compressible, elastic, transparent body, without colour, invisible, and incondensable by any degree of cold that can be produced in the temperature of this earth. It never becomes the constituent part of any body; though its bases, that is, oxygen and azote, enter into the composition of many.

The FLUIDITY of the air is caused by the matter of fire or heat, which produces in it a degree of elasticity



**elasticity** which always tends to dilate the mass, and which preserves the motion of its parts. If the air was not elastic, it might be formed into a hard body, like snow, when its particles are pressed forcibly together.

It is easy to prove that air adheres, with a considerable degree of force, to the surface of bodies; for when water is put into a vessel and heated, the stratum of air which adheres to the sides of the vessel, and which occupies a situation between the water and the sides, soon becomes perceptible there in the form of bubbles, in consequence of the rarefaction which is caused by the heat. It becomes sensible in the same manner in vacuo, in consequence of the dilation occasioned by the pressure being removed \*.

The ancients knew air to be a fluid, but their imperfect knowledge of those substances in general, appears to have disabled them from using those means which the moderns have employed for drawing off and expelling this fluid from a certain space. They were, indeed, utterly unacquainted with the fact, that air is a ponderous fluid. They admitted that there were two kinds of bodies in nature; heavy bodies, such as stones, metals, and in general all bodies which, being left to themselves, had a propensity to descend; and light bodies, such as air, flame, vapours, &c. because these bodies appeared to them to ascend spontaneously into the upper regions of the atmosphere. They supposed, therefore, agreeably

\* Briffon, Tom. ii. p. 93.

to this sentiment, that air was endued with absolute levity; and that all the effects which the moderns attribute to the principle of gravitation, were to be ascribed to the *horror* which nature had, according to them, for a *vacuum*. It was, therefore, a long prevailing opinion, that air was destitute of weight; and it is not above a hundred and fifty years since philosophers have been convinced of this error. The engineers of the Count de Medici, Great Duke of Florence, having received orders to raise some water fifty or sixty feet by means of a common pump, perceived, when they made the attempt, that water would mount only to a certain height, after which it appeared to them, by the void space which they found, that nature was reconciled to a vacuum, or at least suffered this defect without those terrible effects which ancient writers had predicted from it. This apparent caprice, on the part of nature, was communicated by the engineers to Galileo, who paid some attention to it; though, previous to this accident, he, as well as all others, had satisfied himself with the common opinion of the *horror* which nature was supposed to entertain for a *vacuum*. He was at length convinced, by reiterated experiments, that water would rise only to about thirty-two feet perpendicular in pumps, and that the remainder of the pipe or tube, if it was longer, would be empty. He could then no longer retain the opinion respecting the horror of a vacuum, but began to conceive that this horror had its

its limits, and that these phenomena might proceed from a physical cause very different from that to which they had hitherto been attributed. What he had suspected, Toricelli, his disciple, proved by direct experiment. He first made it appear in the year 1645, that a column of air, as it exists in the atmosphere, may be placed in equipoise with a column of another fluid, which has the same base; at length, to avoid the inconvenience of a long pipe, instead of water he made use of mercury. He took a glass tube (Fig. 5.) of two or three inches diameter, hermetically sealed \* at one end, and open at the other; he filled it with pure mercury, and having stopped the orifice with his finger, he reversed the tube, and placed the open end in a vessel full of the same mercury. He had no sooner removed his finger than the column of mercury, which was about thirty-six inches long, was reduced to the length of about twenty-eight inches. Now, if we compare the experiment of Galileo with that of Toricelli, we shall find that fluids act in counterpoise to each other, exactly in proportion to their respective densities; and that the same cause (the pressure of the air) which elevates water to the height of thirty-two feet, cannot sustain a column of mercury above the height of twenty-eight or thirty inches.

Paschal added considerably to the proofs of this

\* Closed by melting the glass, and consolidating it.

doctrine which Torricelli had afforded, and he reasoned in this manner:—If, said he, the air is the cause of this phenomenon, it is because it has ponderance and fluidity; it must press, therefore, in the same manner as liquids, and its pressure must be greater or less according to its height; and every column of whatever fluid is placed in counterpoise with it, will always be longer or shorter in proportion to its density. Hence he proceeded to prove, that a column of air must produce a pressure greater or less, and was capable of sustaining a column of any fluid higher or lower in proportion to its own height, and consequently that a column of water or mercury, at the bottom of a mountain, would rise higher in the Torricellian vacuum than at the summit. M. Paschal next prevailed upon his brother-in-law, M. Perrier, who was at Clermont in Auvergne, to make the following experiment at the base and summit of the mountain, known by the name of *Puy de Dome*.

M. Perrier placed a tube of Torricelli's upon a perpendicular plank (see Fig. 5.) graduated into inches and lines; and having observed to what height the mercury was raised in the tube at the foot of the mountain, he found that it fell gradually in proportion as he ascended towards the summit; and also, on the contrary, that it rose again in the same proportion as he descended: the difference was found to be three inches and one line between the height of the mercury at the summit and the base. This experiment, suggested by *Paschal*, and repeated several

veral times, always produced the same result; whence it was concluded, that mercury was sustained above its level in the Torricellian tube, by the pressure of the atmosphere upon the reservoir, since the mercury in the tube was observed to fall, when the column of air which had the reservoir for its base was diminished in height. These experiments, in proving incontrovertibly the weight of air, have authentically restored to this fluid a great number of natural properties and effects, which were before attributed to a cause merely chimerical.

M. Paschal afterwards repeated the same experiment with water, wine, oil, &c. and the heights of the columns of these liquors were always found to be proportional to their densities; an evident proof that they were counterpoised by a weight, which could in those cases be no other than the pressure of the air.

Many philosophers afterwards, having procured *Torricellian* tubes, placed them according to the manner of M. Perrier, upon a scale graduated into inches and lines, and by frequent observations they perceived, that the height of the mercury in the tube often varied. They concluded, therefore, that the pressure of the air, which was the cause of the suspension of the column of mercury, was sometimes greater and sometimes less, and consequently that it acted more or less forcibly upon the human frame. From these causes and effects the idea was suggested, of making from the *Torricellian* tube a new meteorological instrument, the same which is

now

now commonly known by the name of a *barometer* \*.

Air acts upon barometers in two modes, by its weight and by its elasticity. The variation, therefore, of the pressure upon the reservoir is produced by two causes, by the variation in the weight of the

\* "To fill a barometer tube, (says Mr. Adams) I take a clean glass tube about thirty-three inches long, and pour quicksilver into it by means of a small paper funnel; you observe, that as the quicksilver rises in the tube, there are bubbles of air left behind in several parts; I continue pouring the quicksilver till it fills the tube within about half an inch of the top. I then apply my finger hard and close upon the top of the tube, and invert it; by which means the air that was on the top, now rising through all the quicksilver, gathers every bubble in its way. I revert the tube or turn it up again, and the bubble of air reascends, and if there are any small bubbles left, carries them away; if, however, any remain, the operation must be repeated. I now fill the tube to the top, and placing my finger on the open end of the tube, plunge that end into this basin of quicksilver; when the end of the tube is perfectly submerged in the quicksilver, I take my finger away, and you see the quicksilver remains suspended in the tube, leaving a vacuum at top. The column of quicksilver is about thirty inches in height; now you will observe that there can be no air in the space between the quicksilver and the top of the tube, for till the finger that closed the orifice in the basin was taken away, that space was filled with quicksilver, and the quicksilver, which was thirty-three inches high, sunk in the tube, and left that space free from air, for no air could get into the tube, unless it could force its way through the quicksilver in the basin, and the thirty inches in the tube; or penetrate through the sealed end of the tube: but as neither of those can be done, it follows, that in the part of the tube which the quicksilver leaves, there must be a vacuum."

*Adams's Lectures. Vol. i, p. 32.*

by

incumbent air, and by that of its elasticity. The weight of air varies according to its density, and its intermixture with other substances which are soluble by it; its elasticity varies according to its density, and the quantity of heat with which it is charged. The greater part of foreign substances which intermix with air only, under the form of elastic fluids, diminish the weight of the column of air, because they are lighter than it; but those substances which are soluble in air augment its density, and consequently its weight, in the same manner that salt dissolved in water increases its weight and density.

The barometer has, therefore, another property, not less useful to philosophers than that which has been already mentioned. It points out the changes of the weather, especially when they are likely to be considerable.

From the numerous observations and experiments, which have been made from time to time upon barometers, the seven following propositions have been established by M. Briffon. “First, That the mean height of mercury in France is twenty-seven French inches and an half. Secondly, That the variations from this height seldom exceed three inches, that is, that its least elevation is twenty-six inches, and its greatest twenty-nine. Thirdly, That these variations become less towards the equator, and greater in the northern climates. Fourthly, That when the mercury falls in the barometer it announces rain or wind, or in general what is called bad weather. Fifthly, On the contrary, when  
the

the mercury rises it announces fine weather. Sixthly, That these predictions fail sometimes, especially if the variations in the height of the mercury are very slow and inconsiderable. Seventhly, That the predictions are almost infallible, when the mercury ascends or descends considerably in a short time; as for example, about one-third of an inch (or three or four lines) in the course of a few hours\*.

Thus in relating the discovery of the barometer, we have seen that philosophers were convinced that an actual vacuum might be formed. The air pump, however, was not discovered till 1654. For the first invention of this, the world is indebted to Otto Gueric, a German; but it was our countryman Boyle who converted it to real uses, it was he who improved it, and applied it to philosophical purposes. In the hands of Gueric it was a mechanical instrument; in those of Boyle it was a truly philosophical machine. By this machine we can with ease empty a glass vessel of its air, and put what bodies into it we think fit. Thus comparing the changes wrought upon bodies by being kept from air, with the same bodies when exposed to air, we come to a knowledge of the effects of air upon bodies in general.

As the air-pump is a machine very generally known, I shall not attempt a new description of it; but for the sake of those readers who are

\* Briffon. Vol. i.



but little acquainted with philosophical apparatus, take the description of it from one of the most popular writers on these subjects, in order that its construction may be the more easily understood.

Having put a wet leather on the plate L L (see Plate XX. Fig. 1.) place the large glass vessel or receiver M with its mouth downwards upon the leather, so that the hole *i* in the plate may be within the glass. Then turning the handle F backward and forward, the air will be pumped out of the receiver by the contrivance of the mechanism below. As the handle F, represented more at large (Fig. 2.) is turned backwards, it raises the sucker or piston *d e* in the hollow barrel B K by means of the toothed wheel E engraining in the toothed rack D *d*: and as the piston or sucker is leathered so tight as to fit the barrel exactly, no air can get between this piston and the barrel, and therefore all the air above *d* in the barrel is lifted up towards B, and a vacuum made in the barrel from *e* to *b*: upon which part of the air in the glass M (Fig. 1.) by its spring rushes through the hole *i* in the brass plate L L along the pipe G G, which communicates with both barrels by the hollow trunk I H K, and pushing up the valve *b* (a valve is a bit of leather that covers a hole as the flapper of a bellows, admitting the air in, but suffering none to go back) the air then raising the valve enters into the vacuity *b e* of the barrel B K. For the air will naturally press into those places where it is least resisted. All this is done by drawing the

handle towards D.—Next turning the handle forward the contrary way towards C, the piston *d* is depressed in the barrel, and as the air which had got into the barrel cannot be pushed back through the valve *b*, for the valve closes like the flapper of a bellows, and will not let the air back the way it came, the air must therefore ascend through an hole in the piston, and escapes through a valve at *d*; and is hindered by that valve from returning into the barrel when the piston is again raised. At the next raising of the piston, a vacuum is again made in the same manner as before, between *b* and *e*, upon which more of the air which was left in the glass receiver M gets out thence, and runs into the more empty barrel B K through the valve *b*. The same thing is effected with regard to the other barrel A I, and as the handle F is turned backwards and forwards, it alternately raises and depresses the pistons in their barrels, always raising one while it depresses the other. And as there is a vacuum made in each barrel when its piston is raised, every particle of air in the receiver M pushes out another through the hole *z* and pipe G G into the barrels, until at last the air in the glass receiver comes to be so much rarefied that it can no longer get through the valves, and then no more can be taken out of the receiver. From which it appears, there is no such thing as making a perfect vacuum in the receiver; for the air that leaves the receiver is driven out by that which remains behind, and there must therefore some portion remain behind at last.

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This is the construction and nature of the air-pump. Some instruments at first contrived only for explaining science, become at last, by frequent use, a part of the science itself, and demand an equal explanation. Such is the case with this; and the reader must pardon some prolixity in the description. There is a cock *k* below the plate *L L*, which being turned lets air into the receiver again. There is a glass tube *l m n* open at both ends, and about thirty-four inches long, the upper end communicating with the hole in the pump plate; and the lower end immersed in quicksilver at *n* in the vessel *N*. To this tube is fitted a wooden ruler *m m*, divided into inches and parts of an inch from the bottom at *n*; where it is upon a level with the surface of the quicksilver, and continued up to the top, a little below *l*, to thirty or thirty-one inches. Now the quicksilver in this tube rises as the air is exhausted in the receiver, for it opens into the receiver through the plate *L L*. And the more the air is exhausted, the more will the quicksilver rise, so that by this means the quantity of air pumped out of the receiver may be very exactly measured \*.

From all the preceding facts, and especially from the experiment of Torricelli, it appears, that air is a PONDEROUS fluid; in other words, that it possesses gravity, and its weight may be easily ascertained.

From a large phial (or rather from a flask, or any glass vessel of a globular form, for reasons that

\* Goldsmith's Philosophy, vol. ii. p. 56.

will afterwards appear) to the neck of which is annexed a stop-cock, the air may be exhausted either by means of the air-pump, or by filling the flask with mercury, and emptying it gradually in a vessel containing a quantity of that fluid, and turning the cock before the neck is entirely extricated, which produces a more perfect vacuum than that made by the air-pump. The vessel thus emptied of its air may be weighed by a nice balance; and this done, re-admit the air by turning the cock, when it will rush in with considerable violence; and though the flask was balanced before, it will now become heavier, and preponderate. The air contained in a quart flask will by this experiment be found to weigh about fourteen grains and a half.

To find the specific gravity of the air, the flask must be filled with pure water, and again weighed. The weight of a cubic foot of pure distilled water is about 1,000 ounces avoirdupois, and of a cubic inch 253 grains and not quite one-fifth\*. Dividing the weight of the water contained in the flask, therefore, by this number of grains, will give the number of its cubic inches; and as this furnishes us with the number of cubic inches of air as well as of water, their relative gravity is easily known. By several very accurate experiments, Mr. Hawksbee fixed the specific gravity of air to that of water to be in proportion as 1 to 885.

\* 253.18 grains. Decimal arithmetic should always be employed in philosophical calculations, for the sake of accuracy.

By means of its gravity, the atmosphere presses with great force upon all bodies, according to the extent of their surface. According to M. Pascal, the quantity of this pressure is not less than 2232 pounds upon every square foot of surface, or upwards of fifteen pounds upon every square inch. Computing, therefore, the surface of a man's body at 15 square feet, the whole pressure, which each person sustains, will be nearly equal to 33,480 pounds. By this enormous pressure we should undoubtedly be crushed in a moment, if every part of our body was not filled with air, or some other elastic fluid, the spring of which is sufficient to counteract the pressure.—“We are fearfully and “wonderfully made!”

The whole quantity of pressure upon the earth must thus be immense, and has been computed equal to that of a globe of lead of sixty miles in diameter.

It is the gravity of the air which causes that strong pressure upon the hand, when it is placed upon the mouth of a receiver open at the top, in which a vacuum has been made by an air pump; for as soon as the air in the receiver has been rarefied by the action of the machine, it is no longer capable of sustaining the exterior pressure of the air, as it would have been if its density had not been altered. It is, therefore, the preponderance of the weight of the exterior air, which presses the hand with such force to the edges of the receiver; and this pressure is according to the size of the

aperture of the receiver, because the column of air is enlarged in proportion to the diameter of the aperture.

Our surprise is excited by observing, that notwithstanding this great pressure upon a glass receiver, when a vacuum is obtained, the glass is not dashed to pieces as might be expected. Its preservation is in a great measure owing to the rotundity of its figure, and to the excess of the exterior surface over the interior; for the substance which composes the body of the vessel resembles, in this case, the substance which composes an arch in a bridge. We may be convinced of the truth of this observation by taking a receiver of another form, that is open at both ends, and covered with a bladder at the top, and beginning to exhaust the air, when the bladder will infallibly be burst by the pressure of the exterior atmospheric air.

This gravity of the atmosphere accomplishes many useful purposes in nature, such as preventing the blood vessels of animals, and the sap vessels of plants, from being too much distended by the expansive power, which has a perpetual tendency to swell them out. On this account we see, that in the operation of cupping, where the pressure of the air is taken off from a particular part, the expansive force instantly acts, and swells out the vessels to a great degree. This is also the reason why the bodies of animals swell when they are put into an air pump. It is owing to the gravity of air that substances remain liquid, which would become aeriform in  
vacuo.

**VACUO.** Salts and oils remain united in air, but separate as soon as that fluid is extracted. When hot water is put under an exhausted receiver, it boils violently; because the pressure of the air being now taken off, there is nothing to prevent it from assuming the state of vapour,

‘ This pressure of the atmosphere,’ says Lavoisier, ‘ causes water to remain in a liquid state till it is raised to 212° of Fahrenheit’s thermometer, the quantity of heat which it receives in a lower temperature being insufficient to overcome the pressure of the atmosphere. Whence it appears, that without this pressure we should not have any permanent liquid, and should only be able to see bodies in that state of existence in the very instant of melting, as the smallest additional heat would instantly separate their particles, and dissipate them through the surrounding medium. Besides, without this atmospheric pressure, we should not even have any aeriform fluids, strictly speaking, because the moment the force of attraction is overcome by the repulsive power of the heat, the particles would separate themselves indefinitely, having nothing to limit their expansion, unless their own gravity might collect them together, so as to form an atmosphere\*.’

Air, being an elastic fluid, is consequently COMPRESSIBLE, as the very word implies; the weight, therefore, of the atmosphere compresses its lower parts, for in low vallies it is more compressed, and

\* Lavoisier’s Elem. of Chemist. p. 8,

has more density than upon high mountains; but this is not the case with water, which not being elastic in its ordinary state, is hardly compressible at all; so that the different portions of the same mass of water have nearly the same density throughout its whole depth.

M. Amontons contends, that there is no fixing any bounds to the condensation of air. Dr. Halley has asserted, in the Philosophical Transactions, that, from the experiments made at London and Florence, it might be safely concluded, that no force whatever is able to reduce air into 800 times less space than that which it naturally possesses on the surface of our earth.

It has been proved by various experiments, that a column of compressed air is diminished in proportion to the augmentation of the pressure by which it is condensed.

The simplest of these experiments is, to pour a quantity of quicksilver into the tube A B C (Plate XIX. Fig. 6.) closed at A, and open at C. When the tube is filled with quicksilver to E, then the air inclosed in the leg A B, will prevent its rising higher than D, and the column D B will be in equilibrio with F B; consequently the quicksilver contained between F D will not at all press on the air between A and D; but the column E F, acting with its whole weight on the quicksilver between F and D, causes it to press on the air at D, and condense it. By increasing the quantity of quicksilver the condensation is increased; and it is found, that



that the spaces into which the air is condensed by different weights are inversely as those weights, or its density is as the pressure it bears.

It is however, very probable, after all, that this compression does not take place in an extreme degree, for we know of no body which can be compressed ad infinitum.

From all that has been stated, and particularly from the experiment of Torricelli, it will be evident, that the common notion of suction is a vulgar error; and that when a fluid rushes spontaneously into a given space, it is in consequence of the air being expelled, or made thinner in that space, than in that which is contiguous to it, when the pressure of the atmosphere acts upon the fluid, and forces it to occupy the space from which the air is either entirely or partially expelled. This is the principle on which the common pump is constructed; for a vacuum being made in the tube by the rising of the piston, the weight of the atmosphere presses upon the circumadjacent water, and forces it up into the body of the pump: but this engine will be more particularly described in treating of hydraulics.

The elasticity of the air is now generally supposed to depend upon the latent heat or fire, which retains it in its fluid form. If we take a bladder well closed at the neck, and containing but a small quantity of air; while this bladder is exposed to the pressure of the atmosphere it will remain in its primitive state, as when the small quantity of air was admitted; but if it is placed under the receiver

ceiver of an air pump, and the machine set in motion to exhaust the air surrounding the bladder, it will begin to open and swell, and that in proportion to the diminution of the density of the air in the receiver \*.

Philosophers have doubted whether this elastic power of the air is capable of being destroyed or diminished. Mr. Boyle endeavoured to discover how long air would retain its spring after having assumed the greatest degree of expansion his air pump could give it; but he never observed any sensible diminution. Desaguliers says, that air, which had been inclosed half a year in a wind gun, had lost none of its elasticity; and Roberval asserts, that he has preserved air in the same manner for sixteen years; and that after that period he observed, that its expansive projectile force was the same as if it had been newly condensed. Dr. Hales and Mr. Hawksbee on the contrary conclude, from other experiments, that the elasticity of the air is capable of being impaired and diminished by a variety of causes.

M. Lavoisier, however, has solved these difficulties, by proving, that the elasticity of all gasses or elastic fluids depends upon that of caloric, which seems to be the most eminently elastic body in nature. Nothing, says he, is more readily conceived, than that one body should become elastic by entering into combination with another body possessed of that quality. 'We must allow that this is only an explanation of elasticity, by an assumption of

\* Brissot, tom. ii. p. 103.

elasticity; and that we thus only remove the difficulty one step farther; and that the nature of elasticity, and the reason for caloric being elastic, remain still unexplained\*.

On the elasticity and compressibility of air depend the structure and uses of the air gun. In these instruments a quantity of air is condensed by various contrivances, in such a manner that the condensing force being removed, a bullet will be sent to a considerable distance with little or no noise, but with great force. 'The common air gun is made of brass, and has two barrels. The middle barrel K A (see Plate XX. Fig. 3.) from which the bullets are shot, and the larger outside barrel, closed up at the end C D, and in this the air is driven and kept condensed, by means of a syringe M, which drives the air in, but suffers none to go back. This syringe having been worked for some time, the air is accumulated in great quantities in the external barrel, and this air may be made to strike upon the ball K by means of the trigger O, which pulls back the spiral R, and this spiral opens a valve behind the ball. When the valve is open, the air condensed in the outward barrel rushes in behind the ball, and drives it out with great violence, so great, that at twenty-six yards distance it would drive through an oak board half an inch thick. If the valve behind K is shut suddenly, one charge of condensed air may make several discharges of bullets. The little pellet guns, in the hands of children, shew also the force and spring of the air; for one

\* Elem. of Chem. p. 22.

pellet stopping the mouth of the gun at one end, and another being driven in at the opposite end, the air contained in the bore of the gun between each pellet is continually condensing, as the hind pellet is driven towards the foremost, till at last the spring becomes so great as to drive the foremost pellet forward with some noise and violence. In the large air-gun, however, the noise is by no means so great: upon its discharge nothing is heard but the sound of a rushing wind; and it is very possible, that what we are vulgarly told of some men killing others by loading their pistols with dumb powder, might have proceeded from the silent effects of the air-gun \*.

The air gun described by the author from whom the above is quoted has been in a great measure superseded by one of a more simple construction, originally invented by the late ingenious Benjamin Martin. It is formed like a common gun, with a single barrel, and the condensed air is contained in a brass ball, which screws on below the lock. The ball is charged with a strong syringe, and is furnished with a stop cock, and screws on the end of the syringe to be charged, and then, when the cock is turned, it may be screwed on to the gun. The bullet is made to fit the barrel very exactly, and is rammed in as the ball of a musket. Each gun is generally furnished with two brass balls, which will contain sufficient air for about twenty discharges; and that which is not in present use may be carried

\* Goldsmith's Philosophy, Vol. II. p. 96.

in the pocket. The gun is charged by turning the cock, which fills a small chamber at the butt end of the barrel with condensed air, when the cock may be turned again to save the rest for further discharges. The pulling of the trigger opens a valve, and the spring of the air forces out the bullet, as in the instrument already described.

The elasticity of the air produces also considerable effects in the natural world; for by insinuating itself into the pores of bodies, and possessing this power of expanding, which is so easily excited, it must necessarily put the particles of bodies into which it insinuates itself into a state of almost perpetual oscillation. The truth of this observation is evinced particularly in the air vessels of plants, which perform the office of lungs; for the contained air, expanding and contracting alternately, according to the increase or decrease of the heat, presses the vessels, and eases them again alternately, thus keeping up a continual circulation in the fluids. Even entire columns of marble have been known to cleave, from the increased elasticity of some small bubbles of air contained in them.

Putrefaction and fermentation are processes depending entirely on the action of the air; for we know by numerous experiments, that neither of these changes will take place in vacuo, even in subjects the most favourably disposed to them.

In speaking of the terrestrial atmosphere it has been intimated, that it is found to be nearly the same as to composition in all climates and in all places, as well  
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upon the tops of high mountains as in the vallies below, but that it is considerably less dense in proportion to the height. The whole globe of the earth is entirely enveloped with it; the whole atmosphere is carried along with the terrestrial orb, both in its diurnal and annual motion, and is a principal operator in the mechanism of nature.

Various means have been devised for ascertaining the height of the atmosphere. ‘These attempts,’ says Mr. Adams, ‘commenced soon after it was discovered, by means of the Torricellian tube, that air is a gravitating substance. Thus it also became known that a column of air, whose base is a square inch, and the height that of the whole atmosphere, weighs fifteen pounds; and that the weight of air is to that of mercury, as 1 to 10,800: whence it follows, that if the weight of the atmosphere is sufficient to raise a column of mercury to the height of thirty inches, the height of the aerial column must be ten thousand eight hundred times as much, and consequently a little more than five miles high.

‘It was not, however, at any time supposed, that this calculation could be just; for as the air is an elastic fluid, the upper parts must expand to an immense bulk, and thus render the calculation above related exceedingly erroneous. By experiments made in different countries, it has been found that the spaces, which any portion of air takes up, are reciprocally proportional to the weight with which it is compressed. Allowances were therefore to be made

made in calculating the height of the atmosphere. If we suppose the height of the whole divided into innumerable equal parts, the density of each of which is as its quantity, and the weight of the whole incumbent atmosphere being also as its quantity, it is evident, that the weight of the incumbent air is every where as the quantity contained in the subjacent part, which makes a difference between the weights of each two contiguous parts of air. By a theorem in geometry, where the differences of magnitudes are geometrically proportional to the magnitudes themselves, it appears that these magnitudes are in continual arithmetical proportion; therefore if, according to the supposition, the altitudes of the air, by the addition of new parts into which it is divided, do continually increase in arithmetical proportion, its density will be diminished, or (which is the same thing) its gravity decreased in continual geometrical proportion.

‘ It is now easy, from such a series, by making two or three barometrical observations, and determining the density of the atmosphere at two or three different stations, to determine its absolute height, or its rarity at any assignable height. Calculations accordingly were made upon this plan; but it having been found that the barometrical observations by no means corresponded with the density which, by other experiments, the air ought to have had, it was suspected that the upper parts of the atmospherical regions were not subject to the  
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same laws with the lower ones. Philosophers, therefore, had recourse to another method for determining the altitude of the atmosphere, viz. by a calculation of the height from which the light of the sun is refracted, so as to become visible to us before it himself is seen in the heavens. By this method it was determined, that at the height of forty-five miles the atmosphere had no power of refraction, and consequently beyond that distance was either a mere vacuum, or the next thing to it, and not to be regarded.

‘ This theory soon became very generally received, and the height of the atmosphere was spoken of as familiarly as the height of a mountain, and reckoned to be as well ascertained, if not more so, than the heights of most mountains are. Very great objections, however, which have never yet been removed, arise from the appearances of some meteors, like large globes of fire, not unfrequently to be seen at vast heights above the earth. A very remarkable one of this kind was observed by Dr. Halley in the month of March 1719, whose altitude he computed to have been between sixty-nine and seventy-three and a half English miles; its diameter two thousand eight hundred yards, or upwards of a mile and a half, and its velocity about three hundred and fifty miles in a minute. Others, apparently of the same kind, but whose altitude and velocity were still greater, have been observed, particularly that very remarkable one, August 18th, 1783, whose distance from the earth could not be less



less than ninety miles, and its diameter not less than the former, at the same time that its velocity was certainly not less than one thousand miles in a minute. Fire balls, in appearance similar to these, though vastly inferior in size, have been sometimes observed at the surface of the earth. Of this kind, one was seen on board the Montague, 4th November, 1749, which appeared as big as a large mill-stone; it broke with a violent explosion.

From analogical reasoning, it seems very probable that the meteors, which appear at such great heights in the air, are not essentially different from those which, like the fire-ball just mentioned, are met with on the surface of the earth. The perplexing circumstances with regard to the former are, that at the great heights above-mentioned, the atmosphere *ought not to have any density sufficient to support flame, or to propagate sound*; yet these meteors are commonly succeeded by one or more explosions, nay, are sometimes said to be accompanied with a hissing noise as they pass over our heads. The meteor of 1719 was not only very bright, insomuch that for a short space it turned night into day, but was attended with an explosion, heard over all the island of Britain, occasioning a violent concussion in the atmosphere, and seeming to shake the earth itself. That of 1783 also, though much higher than the former, was succeeded by explosions; and, according to the testimony of several people, a hissing noise was heard as it passed. Dr. Halley acknowledged, that he was unable to reconcile these cir-

cumstances with the received theory of the height of the atmosphere; as, in the regions in which this meteor moved, the air ought to have been three hundred thousand times more rare than what we breathe, and the next thing to a perfect vacuum.

• In the meteor of 1783, the difficulty is still greater, as it appears to have been twenty miles farther up in the air. Dr. Halley offers a conjecture, indeed, that the vast magnitude of such bodies might compensate for the thinness of the medium in which they moved; whether or not this was the case, cannot indeed be ascertained, as we have so few data to go upon; but the greatest difficulty is to account for the brightness of the light. Appearances of this kind are, indeed, with great probability, attributed to electricity, but the difficulty is not thus removed; though the electrical fire pervades with great ease the vacuum of a common air-pump, yet it does not in that case appear in bright well defined sparks as in the open air, but rather in long streams resembling the aurora borealis. From some late experiments, Mr. Morgan concludes that the electrical fluid cannot penetrate a perfect vacuum. If this should be the case, it shews that the regions we speak of are not such a perfect vacuum as can be artificially made; but whether they are or not, the extreme brightness of the light shews that a fluid was present in those regions, capable of confining and condensing the electric matter as much as the air does at the surface of the ground; for the brightness of these  
2 meteors,

meteors, considering their distance, cannot be supposed inferior to that of the brightest flashes of lightning.

‘ It appears, therefore, that the absolute height of the atmosphere is not yet determined. The beginning and ending of twilight, indeed, shew, that the height at which the atmosphere begins to refract the sun’s light is about forty-four or forty-five English miles. But this may, not improbably, be only the height to which the aqueous vapours are carried; for it cannot be thought any unreasonable supposition, that light is refracted only by means of the aqueous vapour contained in the atmosphere: and where this ceases, it is still capable of supporting the electric fire at least as bright and strong as at the surface. That it does extend much higher, is evident from the meteors already mentioned; for all these are undoubtedly carried along with the atmosphere; otherwise that of 1783, which was seen for about a minute, must have been left one thousand miles to the westward, by the earth flying out below it in it’s annual course round the sun \*.’

\* Adams’s Lectures, vol. i. p. 52.

## CHAP. X.

## OF SOUND.

*Sound considered in Three Points of View.—Caused by a Vibration in the Parts of Bodies.—Propagated by an undulatory Motion of the Air.—This proved by Experiment.—Glasses broken by an Effort of the Voice.—Elastic Fluids not the only Means of transmitting Sound.—Water or solid Bodies convey it.—Velocity of Sound.—Experiments on this Subject.—Echoes.—Whispering Gallery.*

**T**HERE is another property of air, which could not so conveniently be introduced into the preceding chapter; I mean the power of transmitting sounds.

Sound is produced by a vibrating motion, excited in a sonorous body by a blow or a shock from another body, and the same motion is communicated by this sonorous body to the fluid which surrounds it, and transmitted by this fluid to the ear, which is an organ admirably adapted to receive its impression.

From this definition it follows, that sound should be considered in three different views; first, with respect to the sonorous body which produces it; secondly, as to the medium which transmits it; and, thirdly, as to the organ which receives the impression.

Those

Those bodies are properly called *sonorous* which afford a sound distinct, and of some duration, such as bells, the strings of a violin, &c. and not those which cause only a confused noise, such as a stone produces when it falls upon a pavement. When bodies are, strictly speaking, sonorous, they are necessarily elastic, as will be afterwards proved; and their sound, as to its force and duration, is proportionate to their vibrations.

Suppose, for example, the bell of a clock to be struck by any solid body, a kind of undulating or tremulous motion is imparted to the minute particles; and this motion may be even perceived by the hand or fingers when applied to the bell.

To understand this more completely, let us conceive that a bell is composed of a series of circular zones, decreasing in diameter all the way to its top, each of which may be considered as a flat ring, composed of as many concentric circles as its thickness will admit of. If this ring is struck at the point *a* (Plate XX. Fig. 4.) the part so struck tends towards *g*, and at the same time the parts *b* and *d* tend towards *i* and *m*, and this action in these parts necessarily causes the point *c* to approach towards *e*; by their elastic power, however, these parts presently regain the position in which they were before the bell was struck; but as they return with an accelerated force, they generally go beyond the point where they ought to rest. The part *a*, therefore, after having returned from *g* to *a*, tends towards *f*, the part *c* towards *b*, and the parts *b*

and  $d$  towards  $k$  and  $l$ , whence it happens that the bell, at first of a circular form, really becomes alternately oval in two different directions; it follows then, that in those parts where the curvature is the greatest, their exterior points depart from each other.

The same circumstance happens to the musical cord of a harp, or other stringed instrument, when it is touched; for, in order to become angular, as  $BCD$  or  $BED$  (Fig. 5.) it is necessary that the string should be stretched or lengthened, and consequently its particles be in some measure removed from the point of contact.

There are then two vibrations which take place in sonorous bodies; the general vibration, which changes the form of the body, and the particular vibration, which affects the minute particles, in consequence of the former. M. de la Hire has proved\*, that the sound is not owing to the general vibration, but rather to the vibration of the particles; for whenever the two vibrations can be separated, it is found that the former produces no sound; but when the general vibration is accompanied with a vibration of the particles, the latter it is that regulates the duration, the force, and the modulation of the sound: if, on the contrary, these vibrations are stopped or interrupted by touching the sonorous body, the sound immediately ceases. On this account clock-makers attach to the hammer, which

\* Mem. de l'Acad. 1726 p. 264.

Fig. 3.



Fig. 5.

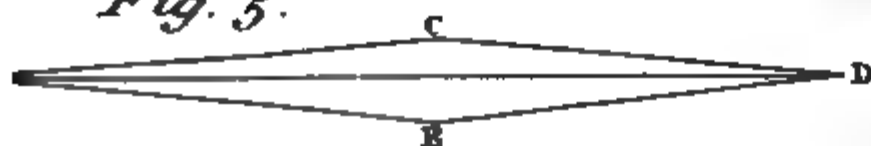


Fig. 4.



Fig. 2.





strikes the bell of the clock, a small spring, which elevates it again the moment it has struck, and prevents it from remaining upon the bell, which would considerably deaden or destroy the sound.

Acute sounds are produced, when the vibrations of the sounding body are more frequent; grave or deep sounds, when they are less so: no medium between acute and grave sounds can be found. Sonorous bodies are said to be in unison when they vibrate with the same frequency; when one vibrates twice as fast as the other, they differ by an octave; and other ratios, with respect to the quickness of vibration, are distinguished by other names. Cords, which are short and tightly stretched, produce acute sounds; those which are long and lax, grave sounds.

The motion or vibration of bodies at a distance from us would not affect our sense of hearing without the medium of some other body, which receives an impulse from this motion, and communicates the vibrations to our organs. Thus a hard blow upon an anvil or upon a bell could not be heard by us, even at a very small distance, if there was not a medium between those objects and us capable of transmitting the vibrations to our auditory nerves. Elastic fluids are the most effective mediums for this purpose, and consequently the air is the most common vehicle of sound, which is very easily proved by ringing a bell under the receiver of an air-pump, the sound it affords being found gradually to diminish as the air becomes exhausted, till at length it ceases to be heard at all. That

the air is capable of being agitated with great force appears from the violent concussions produced by explosions of gunpowder, as well as from the power, which some persons are known to possess, of breaking drinking-glasses by means of their voice, when sounded in unison with the note which the glass would have produced when struck. The tremulous motion excited in the air by sounding bodies has been supposed analogous to the successive rings which are produced by disturbing the surface of water. This hypothesis, however, was disproved by the observation that sounds, whether weak or loud, always travel with the same velocity, which does not hold true with respect to the rings on the surface of water, since these move faster or slower according to the force of the cause which excited them.

Every sound is rendered stronger or weaker, and may be heard at a greater or less distance, according to the density \* or rarity of that elastic fluid, by which it is propagated. According to Mr. Hauksbee, who has made deep researches into this branch of philosophy, when air has acquired twice its common density it transmits sound twice as far as common air; whence he reasonably concludes, that sound increases, not only in direct proportion

\* That some degree of density is necessary in a fluid, to enable it to convey sounds, is evident from this fact, that light, which is a fluid extremely rare, is totally destitute of this power.—*Traité Elem. de Physique*, tom. ii. p. 162.

to the density of the air, but in proportion to the square of this density.

If sound was propagated in an elastic fluid more dense than the air, it would be carried proportionably farther. I have proved this, says M. Brisson\*; by putting a sonorous body into carbonic acid gas or fixable air, the density of which is about one-third more than that of atmospherical air; the consequence was, that at that time, and in that situation, the sound was very considerably increased. For the same reason, the dryness of the air, which increases its density, has a considerable effect in rendering sound louder and more audible. Sound is also much increased by the reverberation of the pulses of the air from those surrounding bodies against which they strike, whence it happens that music is so much louder in a close apartment than in the open air.

Elastic fluids are, however, not the only mediums through which sound may be transmitted; for it may be propagated by means of water and other liquors, which may be proved by immersing a sonorous body in water; but it must be observed, that in this case the sound will be less perceptible, and will not extend to so great a distance; the cause of this diminution is, because mediums for the transmission of sound should be elastic, and that is a property which water and other liquors possess only in a very restricted degree.

\* Elem. de Physique, tom. ii. p. 164.

Sound is also transmitted by solid bodies, provided they possess a sufficient degree of elasticity to produce this effect.

Light, we have already seen, is projected or reflected with incredible velocity; but sound is transmitted much more slowly, and its progression is very perceptible to our senses. The flash from a cannon, or even a musket, may be seen some seconds before the sound reaches our ears. As the motion of light, therefore, is instantaneous with respect to any moderate distance, this has been the common means employed for ascertaining the progress of sound. Sir Isaac Newton observes, that "all sounding bodies propagate their motions on all sides by successive condensations and relaxations; that is, by an alternate progression and return of the particles;" and these vibrations, when communicated to the air, are termed pulses of sound.

All pulses move equally fast. This is proved by experiment; and it is found that they pass about one thousand one hundred and forty-two feet in a second, whether the sound is loud or low, grave or acute\*.

Some

\* That we labour under a deception with regard to tones, and that they become higher as they come from a greater distance, may be inferred from musical composition. The greatest masters in this art, when they would imitate a distant echo, generally take the sounds an octave higher. A few years ago, a fellow exhibited in Westminster the art of imitating sounds at any distance whatever. I remarked, that whenever he designed to imitate a voice coming from a great distance, he not only made the sound more low and indistinct, but raised the tone several

Some curious experiments were made, relative to the propagation of sound, by Messieurs de Thury, Maraldi, and de la Caille, upon a line fourteen thousand six hundred and thirty-six fathoms in length, having the tower of Mount Lhéri at one end, and the pyramid of Montmartre at the other extremity of that distance: their observatory was placed between those two objects. The result of their observations were these, 1st. That sound moves one hundred and seventy-three fathoms French in a second, when the air is calm. 2d, That sound

veral pitches higher than that used in his nearer imitations. A few observations since made upon sounds, induce me to believe, that they become higher as they come from a distance more remote; while, on the contrary, that they deepen the more the vibrations approach the labyrinth of the ear. The following easy and common experiment, I think, will prove it. Take any thing whatever, capable of giving a sound; let it be a common poker for instance, and tying on a garter at top, so as that both ends of the garter are left at liberty; these ends must be rolled round the first finger of each hand, and then with these fingers stopping the ears close, strike the poker thus suspended against any body whatsoever. The depth of the tone which this new musical instrument returns will be amazing. The deepest and largest bell will not equal it. Whence is this, unless from the close approach of the sounding body, whose vibrations are immediately communicated to the internal parts of the ear. I am sensible that many objections may be made to this last opinion; succeeding experience must, however, determine whether it be just or not: but such as make them must be particularly careful not to let their former experience correct their immediate sensations. This alteration of tone, with distance, however, must diminish but by great intervals. *Goldsmith's Philosophy*, vol. ii. p. 195, 196.

moves

moves with the same degree of swiftness whether it is strong or weak; for these gentlemen observed, that the discharge of a box of half a pound of gun-powder exploded at Mountmartre was heard at Mount Lhéri in the same space of time as the report of a great gun charged with nearly six pounds of powder. 3d. That the motion of sound is uniform; that its velocity neither accelerates nor diminishes through all the intervals of its progress, as is the case with almost every other species of motion. 4th. That the velocity of sound is the same; whether a cannon is placed towards the person who hears its report, or turned a contrary way; in other words, a great gun fired from the Tower of London eastward, would be heard at Westminster in the same interval of time as if it was discharged towards the latter place. And if the gun was discharged in a direction perpendicular to the horizon, it would be heard as soon as if discharged in a right line towards the hearer. By other experiments, however, the progress of sound appears to be impeded by a strong wind, so that it travels at the rate of about one mile slower in a minute against a strong wind than with it.

A knowledge of the progression of sound is not an article of mere sterile curiosity, but in several instances useful; for by this we are enabled to determine the distance of ships or other moving bodies. Suppose, for example, a vessel fires a gun, the sound of which is heard five seconds after the flash is seen; as sound moves 1142 English  
lish

lish feet in one second, this number multiplied by 5 gives the distance of 5710 feet. The same principle has been already noticed as applied to storms of lightning and thunder.

The waves or pulses of sound being reflexible in their course when they meet with an extended solid body of a regular surface, an ear placed in the passage of these reflected waves will perceive a sound similar to the original sound, but which will seem to proceed from a body situated in a similar position and distance behind the plane of reflection, as the real sounding body is before it. This reflected sound is commonly called an ECHO, which, however, cannot take place at less than fifty-five feet; because it is necessary that the distance should be such, and the reverberated or reflected sound so long in arriving, that the ear may distinguish clearly between that and the original sound \*.

#### Reflected

\* “ It is in general known, that caverns, grottoes, mountains, and ruined buildings return this image of sound. Image we may call it, for in every respect it resembles the image of a visible object reflected from a polished surface. Our figures are often represented in a mirror without seeing them ourselves, while those standing on one side are alone sensible of the reflection. To be capable of seeing the reflected image of ourselves, we must be directly in a line with the image. Just so is it in an echo; we must stand in the line in which the sound is reflected, or the repetition will be lost to us, while it may, at the same time, be distinctly heard by others who stand at a small distance to one side of us. I remember a very extraordinary echo, at a ruined fortress near Louvain, in Flanders. If a person sung, he only heard his own voice, without any repetition;

on

Reflected sound may be magnified by much the same contrivances as are used in optics respecting

on the contrary, those who stood at some distance, heard the echo but not the voice; but then they heard it with surprising variations, sometimes louder, sometimes softer, now more near, then more distant. There is an account, in the memoirs of the French academy, of a similar echo near Rouen. The building which returns it is a semicircular court-yard; yet all buildings of the same form do not produce the same effects. We find some music halls excellently adapted for sounds, while others, built upon the same plan, in a different place, are found to mix the tones, instead of enlarging them, in a very disagreeable manner.

“ As we know the distance of places by the length of time a sound takes to travel from them, so we may judge of the distance of an echo, by the length of the interval between our voice and its repetition. The most deliberate echoes, as they are called, are ever the most distant; while, on the contrary, those that are very near, return their sounds so very quick as to have the interval almost imperceptible; when this is the case, and the echo is so very near, the voice is said to be increased and not echoed; however, in fact, the increase is only made by the swiftly pursuing repetition. Our theatres and concert rooms are best fitted for music or speaking, when they enlarge the sound to the greatest pitch at the smallest interval: for a repetition which does not begin the word till the speaker has finished it, throws all the sounds into confusion. Thus the theatre at the Hay-market enlarges the sound very much; but then at a long interval after the singer or speaker. The theatre at Drury-lane, before it was altered, enlarged the sound but in a small degree; but then the repetition was extremely quick in its pursuit, and the sounds, when heard, were therefore heard distinctly. Dergolife, the great musical composer, used to say, that an echo was the best school-mistress; for let a man's own music be ever so good, by playing to an echo she would teach him to improve it.” *Goldsmith's Philosophy*, vol. ii. p. 201—204.

light:



light : hence it follows, that sounds uttered in one focus of an elliptical cavity are heard much magnified in the other focus. The whispering gallery at St. Paul's cathedral in London is of this description ; a whisper uttered at one side of the dome is reflected to the other, and may be very distinctly heard. The speaking and ear trumpets are constructed on this principle. The best form for these instruments is a hollow parabolic conoid, with a small orifice at the top or apex, to which the mouth is applied when the sound is to be magnified, or the ear when the hearing is to be facilitated.

The structure of the ear is one of the most complicated and difficult subjects of physiology, and it could scarcely be comprehended without some previous knowledge of the constituent parts of the animal frame ; for this reason it will be necessary to defer the consideration of the manner in which we receive ideas of sound, till I come to treat of that part of the animal œconomy which respects the sense of hearing.

## C H A P. XI.

## W I N D S.

*Different Opinions concerning the general Cause of Winds.—Of General or Trade Winds.—Of Monsoons.—Of Sea and Land Breezes.—Causes of these.—Variable Winds.—Storms.—Hurricanes.—The Harmattan.—The Sirocco Wind.—The Samiel.—Moving Pillars of Sand.—The Simoom.—Whirlwinds.—Water-spouts.—Tornadoes.*

**T**HE opinions of philosophers have varied much respecting the cause of winds, and many of their theories are little more than mere conjectures; but it must be confessed, that electricity and a chemical knowledge of air have latterly in some degree improved our imperfect acquaintance with these aerial currents.

It has been already observed, that air is expanded by heat, and its spring consequently increased; and it is well known also that its elasticity is weakened by cold or freezing mixtures. From experiments which have been made for the illustration of these properties of air, we are enabled to point out the causes of many phenomena that occur in the atmosphere.

When a fire is made in the open air, the rarefied part of that fluid will ascend in a current, and the cooler and denser air will rush in on all sides, in consequence of which a wind is generated,  
which

which blows constantly towards the fire: The wind produced in this manner will be too inconsiderable to be perceived at any great distance, but the rarefactions which arise from natural causes may be such as to agitate our atmosphere sufficiently to produce those torrents of air which have always a powerful effect in nature, and which sometimes overwhelm and destroy the fairest productions of human art.

M. Briffon is inclined to believe, that electricity is the first and general cause of all variable winds: ‘Thunder and water-spouts\*,’ says he, ‘are now acknowledged to be electrical phenomena, and these are frequently accompanied with formidable winds. Why may not the cause which produces these phenomena be also that of the winds which accompany them? If electricity is the cause of these winds, why may it not be the cause of the others †?’

Winds are commonly divided into three classes, viz. general, periodical, and variable winds.

General or permanent winds blow always nearly in the same direction. In the Atlantic and Pacific Oceans, under the equator, the wind is almost always easterly; it blows, indeed, in this direction, on both sides of the equator to the latitude of  $28^{\circ}$ . More to the northward of the equator, the wind generally blows between the north and east, and the far-

\* Of the latter I entertain many doubts, at least as to electricity being the proximate or efficient cause. See the latter part of this chapter.

† Briffon, *Traité Elem. de Physique*, tom. ii. p. 180.

ther north we proceed, we find the wind to blow in a more northern direction; more to the southward of the equator it blows between the south and east, and the farther to the south, the more it comes in that direction.

Between the parallels of  $28^{\circ}$  and  $40^{\circ}$  south lat. in that tract which extends from  $30^{\circ}$  west to  $100^{\circ}$  east longitude from London, the wind is variable, but it most frequently blows from between the N. W. and S. W. so that the outward bound East India ships generally run down their easting on the parallel of  $36^{\circ}$  south\*.

Navigators have given the appellation of *trade-winds* to these general winds.

Those winds, which blow in a certain direction for a time, and at certain stated seasons change and blow for an equal space of time from the opposite point of the compass, are called *monsoons*. During the months of April, May, June, July, August, and September, the wind blows from the southward over the whole length of the Indian Ocean; viz. between the parallels of  $28^{\circ}$  N. and  $28^{\circ}$  S. lat. and between the eastern coast of Africa and the meridian which passes through the western part of Japan; but in the other months, October, November, December, January, February, and March, the winds in all the northern parts of the Indian Ocean shift round, and blow directly contrary to the course they held in the former six months. For some days before and after the change,

\* See Nicholson's Phil. vol. ii. p. 56.

there

there are calms, variable winds, and tremendous storms, with thunder, &c.

Philosophers differ in their opinions respecting the cause of these periodical winds; but a most probable theory of the general trade-winds is, that they are occasioned by the heat of the sun in the regions about the equator, where the air is heated to a greater degree, and consequently rarefied more than in the more northern parts of the globe. From this expansion of the air in these tropical regions, the denser air, in higher latitudes, rushes violently towards the equator from both sides of the globe. By this conflux of the denser air, without any other circumstances intervening, a direct northerly wind would be produced in the northern tropic, and a southern one in the other tropic; but as the earth's diurnal motion varies the direct influence of the sun over the surface of the earth, and as by that motion this influence is communicated from east to west, an easterly wind would be produced; if this influence alone prevailed. On account of the co-operation of these two causes at the same time, the trade-winds blow naturally from the N. E. on the north, and from the S. E. on the south of the line; throughout the whole year; but as the sun approaches nearer the tropic of *Cancer* in our summer season, the point towards which these winds are directed will not be invariably the same, but they will incline more towards the north in that season, and more towards the south in our winter.

The *land* and *sea breezes* in the tropical climates may be considered as partial interruptions of the ge-

neral trade winds, and the cause of these it is not very difficult to explain. From water being a better conductor of heat than earth, the water is always of a more even temperature. During the day, therefore, the land becomes considerably heated, the air rarefied, and consequently in the afternoon a breeze sets in from the sea, which is less heated at that time than the land. On the other hand, during the night the earth loses its surplus heat, while the sea continues more even in its temperature. Towards morning, therefore, a breeze regularly proceeds from the land towards the ocean, where the air is warmer, and consequently more rarefied than on shore.

The cause of the monsoons is not so well understood as that of the general trade winds; but what has been just remarked, suggests, at least, a probable theory on the subject. It is well known, that at the equator the changes of heat and cold are occasioned by the *diurnal* motion of the earth, and that the difference between the heat of the day and the night is almost all that is perceived in those tropical regions; whereas in the polar regions the great vicissitudes of heat and cold are occasioned by the *annual* motion of the globe, which produces the sensible changes of *winter* and *summer*; consequently, if the heat of the sun was the only cause of the variation of the winds, the changes, if any, that would be produced by those means in equatorial regions, ought to be *diurnal* only, but the changes about the *pole* should be experienced only once in six months. As the effects arising from the heat of the sun upon the air must be greater at the equator than at the poles, the changes of the  
wind

wind arising from the expansion of the air by the sun's rays must be more steady in equatorial than in polar regions. The incontrovertible evidence of navigators proves this truth, that winds are more variable towards the poles, and more constant towards the equator. But in summer, the continual heat, even in high latitudes, comes to be sensibly felt, and produces changes on the wind, which are distinctly perceptible. In our own cold region, the effects of the sun on the wind are felt during the summer months; for while the weather in that season of the year is fine, the wind generally becomes stronger as the time of the day advances, and dies away towards the evening, and assumes that pleasing serenity so delightful to our feelings. Such are the diurnal changes of the wind in northern climates. The *annual* revolution of the sun produces still more sensible effects. The prevalence of the western winds during summer, we may attribute to this cause, which is still more perceptible in France and Spain; because the continent of land to the eastward, being heated more than the waters of the Atlantic Ocean, the air is drawn, during that season, towards the east, and consequently produces a western wind.

But these effects are much more perceptible in countries near the tropics than with us. For when the sun approaches the tropic of Cancer, the soil of Persia, Bengal, China, and the adjoining countries, becomes so much more heated than the sea to the southward of those countries, that the current of the general trade wind is

interrupted, so as to blow, at that season, from the south to the north, contrary to what it would do if no land was there. But as the high mountains of Africa, during all the year, are extremely cold, the low countries of India, to the eastward of it, become hotter than Africa in summer, and the air is naturally drawn thence to the eastward. From the same cause it follows, that the trade wind, in the Indian Ocean, from April till October, blows in a north-east direction, contrary to that of the general trade wind, in open seas, in the same latitude; but when the sun retires towards the tropic of Capricorn, these northern parts become cooler, and the general trade wind assumes its natural direction.

Having given the most obvious causes of the periodical monsoons in the Indian seas, it is necessary to observe, that no monsoon takes place to the southward of the equator, except in that part of the ocean adjoining to New Holland. There the same causes concur to produce a monsoon as in the northern tropic, and similar appearances take place. From October till April the monsoon sets in from the N. W. to S. E. opposite to the general course of the trade wind on the other side of the line; and here also the general trade wind resumes its usual course during the other months, which constitute the winter season in these regions. It may not be improper to conclude this account of the tropical winds, by enumerating some of the principal inflections of the monsoons.

Between



Between the months of April and October the wind blows constantly from W. S. W. in all that part of the Indian ocean which lies between Madagascar and Cape Commorin, and in the contrary direction from October till April, with some small variation in different places; but in the bay of Bengal these winds are neither so strong nor so constant as in the Indian ocean. It must also be remarked, that the S. W. winds in those seas are more southerly on the African side, and more westerly on the side of India; but these variations are not so great as to be repugnant to the general theory. The cause of this variation is, as was before intimated, that the mountainous lands of Africa are colder than the flatter regions of Arabia and India, consequently the wind naturally blows from these cold mountains, in the summer season, towards the warmer lands of Asia, which occasions those inflections of the wind to the eastward during the summer months. The peninsula of India, lying so much farther to the south than the kingdoms of Arabia and Persia, adds greatly to this effect, because the wind naturally draws towards them, and produces that easterly variation of the monsoon which takes place in this part of the ocean, while the sandy deserts of Arabia draw the winds more directly northward, near the African coast. A similar chain of reasoning will serve to explain any other inflexions or variations that may occur in the perusal of books of travels, &c.

The variable winds, which take place in these climates, depend upon different causes; but I am inclined to agree with M. Briffon in attributing them

chiefly to electricity. It is to be remembered, that whatever destroys the equilibrium of the air, in other words, any cause which produces a sudden rarefaction in any part of the atmosphere, produces a current of wind towards the part where the rarefaction takes place; winds are, therefore, not only produced by the earth being heated in a particular part, but by thunder storms or other electrical phenomena. The rays of the sun are also sometimes obstructed by clouds or mists in particular places, and one part of the world, or even of a particular country, will consequently be less heated than another; in that case there will always be a current of air from the cold to the warm region. Besides this, the falling of rain, or other circumstances, produce occasional alterations in the temperature; and whenever these take place in any country, they must be attended with wind. The great Bacon was the first who attempted a theory of the wind; and it is to be lamented that his plan has not been pursued by succeeding philosophers. The following is a sketch of his general principles, with a few additions by modern observers.

‘ At sea the winds are more regular than at land; for there nothing opposes their progress, or alters the sun’s influence.

‘ The air at sea is more equable, as well as more constant: at land it blows in fits of force and intermission; but at sea the current is strong, steady, and even.

‘ In general, at sea, on this side the equator, the east and north winds are most violent and boisterous:

ous: on the contrary, at land, the west and south winds are most subject to produce hurricanes and tempests.

The air is often seen to move in two contrary currents, and this almost ever previous to thunder. The clouds, in such a case, are seen to move one way, while the weathercock points another.

The winds are more violent at certain heights than upon the plain, and the higher we ascend lofty mountains, the greater is the force of the wind, till we get above the ordinary height of the clouds. Above this the sky is usually serene and clear. The reason is, that the wind, at the surface of the earth, is continually interrupted by hills and risings: so that, on the plain, between any two of these, the inhabitants are in a kind of shelter; but when once the interposition of small hills no longer stops the wind's course, it then becomes stronger, as the interruptions it meets with are fewer. At the tops of the higher mountains its interruptions are least of all; but it does not blow with violence there; for its density is so much diminished by the height, that its force is scarcely perceptible, and the storm falls midway below. What is commonly called a high wind moves at the rate of about thirty-five miles an hour.

A current of air always augments in force in proportion as the passage through which it runs is diminished. The law of this augmentation is, that the air's force is compounded of its swiftness and density, and as these are increased, so will the force of the wind. If any quantity of wind moves with  
twice

twice the swiftness of a similar quantity; it will have twice its force; but if, at the same time that it is twice as swift, it moves through twice a smaller tube, and the sides of the canal give no resistance to its motion, it will have four times the force. This, however, is not entirely the case; for the sides of the tube give a resistance, and retard its motion, in a proportion that is not easily calculated. From this increase of the wind's density in blowing through narrow passages, it is that we see the storms so very violent that sometime blow between two neighbouring hills. It is from this, that when caught in long arcades opening at one end, the wind blows with great force along them. From this increased density it is, that we meet with such cold blasts at the corners of streets. In short, whatever diminishes its bulk, without taking entirely away from its motion, increases the vehemence of the wind. This also is the reason why the air reflected back from the side of a mountain is often more violent than the air which first struck its side; for it is by this means condensed, and its force augmented. The countrymen and farmers have a distinction which is not without its foundation; for they make a difference between a swift and an heavy storm: the swift storm is loud, boisterous, and inoffensive; the heavy storm more boisterous and also more dangerous. This shews the insufficiency of those instruments made for measuring winds, by measuring the rapidity only with which they move \*.

\* Goldsmith's Philosophy, vol. ii. p. 143.

It would be happy indeed for science and for mankind if these researches could have been carried further. To predict an eclipse, says a late writer, is an object merely of curiosity; to predict an approaching storm would be of inconceivable benefit. What is still unaccomplished with respect to our own climate, has however been attempted with respect to those alarming storms which happen in the West Indies, which are commonly denominated hurricanes.

These dreadful convulsions of nature, Dr. Perkins supposes to be caused by some occasional obstruction in the usual and natural progress of the equatorial trade winds. The reason he assigns for this conjecture is, the more than usual calm which commonly precedes them. In the natural course of the trade winds, the air rises up in the line, and passes off towards the poles, and, in the more contracted degrees of the higher latitudes, takes the course of the west trade winds, so that could their ascent be prevented through the whole circle of the zone, there would be no more west winds in those latitudes than in any other. Very violent rains and cold, however, tend to check the ascent of air out of this circle, rather causing it to descend. Great clouds and vapour generate cold and wet, while rain beats down the air; and as these prevent the rising of the air out of the line, so they hinder its usual progress from the tropics on both sides; hence the calms which usually precede hurricanes. Calms, in these tropical regions, are caused by the  
5 ascent

ascent of the air into the higher part of the atmosphere, instead of its remaining near the line: the accumulation of air above then becomes heavier by the cold which it meets in those regions, and descends into the more rarefied region below. These heavy gales, therefore, will continue to descend till the upper regions are entirely exonerated.

In Mr. Beckford's history of Jamaica there is a very detailed and striking account of the dreadful hurricane which desolated the islands in the year 1780, but it is too long for insertion as an extract, and in an abridged state the description would lose its force: 'It is in the rainy season (says Mr. Adams) principally in the month of August, that they are assailed by hurricanes, which destroy at a stroke the labours of many years, and prostrate the most exalted hopes of the planter, and that, often when he thinks himself out of the reach of fortune. It is a sudden and violent storm of wind, rain, thunder, and lightning, attended with a furious swelling of the seas, and sometimes with an earthquake; in short, with every circumstance which the elements can assemble, that is terrible and destructive. First, they see, as a prelude to the ensuing havock, whole fields of sugar canes whirled into the air, and scattered over the face of the country. The strongest trees of the forest are torn up by the roots, and driven about like stubble; their wind-mills are swept away in a moment; their works, the fixtures, the ponderous copper-boilers, and stills of several hundred weight, are wrenched from the ground and  
battered

attered to pieces; their houses are no protection; their roofs are torn off at one blast, whilst the rain, which in an hour rises five feet, rushes in upon them with irresistible violence.

There are signs by which the Indians of these islands taught our planters to prognosticate the approach of an hurricane. The hurricane comes on either in the quarter or at the full change of the moon. If it comes on at the full, then, at the preceding change, the sky is troubled, the sun more red than usual; there is a dead calm below, and the mountain tops are free from those mists which usually hover about them. In the caverns of the earth, and in wells, you hear a hollow rumbling sound, like the rushing of a great wind. At night the stars seem much larger than usual, and surrounded with a sort of burs; the north-west sky has a black and menacing appearance; the sea emits a strong smell, and rises into vast waves often without any wind. The wind itself now forsakes its usual steady easterly stream; and shifts about to the west; whence it sometimes, with intermissions, blows violently and irregularly about two hours at a time. You have the same signs at the full moon: the moon herself is surrounded with a great bur, and sometimes the sun has the same appearance\*.

The harmattan is a very singular wind, which blows periodically from the interior parts of Africa towards the Atlantic Ocean. The season in which it prevails is during the months of December, Ja-

\* Adams's Lectures, vol. iv. p. 540.

nuary, and February; it comes on indiscriminately at any hour of the day, at any time of the tide, or at any period of the moon, and continues sometimes only a day or two, sometimes five or six days, and it has been known to last fifteen and sixteen days. There are generally three or four returns of it every season. It blows with a moderate force, but not quite so strong as the sea breeze.

A fog or haze is one of the peculiarities which always accompany the harmattan. The English, French, and Portuguese forts at Whydah, are not quite a quarter of a mile asunder, yet are frequently quite invisible to each other; the sun, concealed the greatest part of the day, appears only about a few hours at noon, and then of a mild red, exciting no painful sensation on the eye. The particles which constitute this fog are deposited on the leaves of trees, on the skins of the negroes, &c. and make them appear whitish.

Extreme dryness makes another extraordinary property of this wind; no dew falls during its continuance; vegetables are withered, and the grass becomes dry like hay. The natives take this opportunity to clear the land, by setting fire to the trees and plants while in that dry and exhausted state. The dryness is so extreme, that the covers of books, even closely shut up in a trunk, are bent as if exposed to the fire. Household furniture is much damaged; the pannels of wainscots split, and fineered work flies to pieces. The joints of a well-laid floor of seasoned wood open sufficiently to admit



nit the breadth of a finger between them; but become as close as before on the ceasing of the harmattan. The human body does not escape the parching effects of this wind; the eyes, nostrils, lips, and palate, are rendered dry and uneasy; the lips and nose become sore, and though the air is cool, there is a troublesome sensation of pricking heat on the skin. If the harmattan continues four or five days, the scarf-skin peels off, first from the hands and face, and afterwards from the rest of the body.

Though this wind is so fatal to vegetable life, and occasions these troublesome effects to the human species, it is nevertheless highly conducive to health; it stops the progress of epidemics, and relieves the patients labouring under fluxes and intermittent fevers. Infection is not easy at that time to be communicated, even by inoculation. It is also remarkable for the cure of ulcers and cutaneous diseases \*.

The sirocco (so called by the Italians because it is supposed to blow from Syria, and in the South of France, the Levant wind) resembles in some of its effects the harmattan, but it differs from it in being extremely insalubrious. It sometimes blows for several days together, to the great annoyance of the whole vegetable and animal creation; its medium heat is calculated at 112 degrees; it is fatal to vegetation and destructive to mankind, and especially to

\* Dobs. Account, Phil. Transf. vol. lxxi. part 1.

strangers;

strangers ; it depresses the spirits in an unusual degree ; it suspends the powers of digestion, so that those who venture to eat a heavy supper while this wind prevails are commonly found dead in their beds the next morning, of what is called an indigestion. The sick, at that afflicting period, commonly sink under the pressure of their diseases ; and it is customary in the morning, after this wind has continued a whole night, to inquire who is dead \*.

‘ An

\* ‘ The evil most to be dreaded in traversing these regions is, perhaps, the *sirocco*, or south wind, which it is imagined blows from the burning deserts of Africa, and is sometimes productive of dangerous consequences to those who are exposed to its fury. During the continuance of this wind all nature appears to languish, vegetation withers and dies, the beasts of the field droop, the animal spirits seem too much exhausted to admit of the least bodily exertion, and the spring and elasticity of the air appear to be lost. The heat exceeds that of the most fervid weather in Spain or Malta, and is felt with peculiar violence in the city and neighbourhood of Palermo.

‘ The sensation occasioned by the *sirocco* wind is very striking and wonderful. In a moment the air becomes heated to an excessive degree, and the whole atmosphere feels as if it were inflamed, the pores of the body seem at once opened, and all the fibres relaxed. During its continuance the inhabitants of Palermo shut their doors and windows to exclude the air, and where there are no window shutters, wet blankets are hung on the inside of the window, and the servants are kept continually employed in sprinkling the apartments with water. No creature, whose necessities do not compel him to the exertion, is to be seen while this tremendous wind continues to blow, and the streets and avenues of the city appear to be nearly deserted.

‘ The *sirocco* generally continues so short a time in Sicily, that it seldom produces those complaints which are the consequence

‘ An extraordinary blasting wind is felt occasionally at Falklands Islands. Happily its duration is short: it seldom continues above twenty-four hours. It cuts the herbage down as if fires had been made under them; the leaves are parched up, and crumble into dust. Fowls are seized with cramps so as never to recover. Men are oppressed with a stopped perspiration, heaviness at the breast, and fore throat; but recover with care.

‘ But beyond all others in its dreadful effects, is the samiel, or mortifying wind, of the deserts near the coast of Sicily. The consequence of the duration of its scorching heats in several parts of Italy, though its violence in those countries is much inferior to what is felt in this island. Here it seldom endures longer than thirty-six or forty hours, a time not sufficient to heat the ground, or the walls of the houses, in a very intense continued degree. It is commonly succeeded by the tramontane, or north wind, which in a short time restores the exhausted powers of animal and vegetable life, and nature soon assumes her former appearance. The cause of the sirocco wind has been frequently attempted to be explained, but the different hypotheses are perhaps more to be admired for their ingenuity and fancy than for being very satisfactorily explained. The superior intenseness of this scorching wind at Palermo, may probably be accounted for from the situation of that city, which is almost surrounded by lofty mountains, the ravines and valleys of which are parched and almost burnt up in summer. The numberless springs of warm water must also greatly increase the heat of the air, and the practice of burning brush wood and heath on the neighbouring mountains, during the warm season, must undoubtedly tend to increase the heat of the wind in passing over the country of Sicily, though it had previously been disarmed of part of its violence by travelling over the sea which divides Sicily from Africa.” *Present State of Sicily and Malta*, p. 189.

Bagdad. The camels, either by instinct or experience, have notice of its approach, and are so well aware of it, that they are said to make an unusual noise, and cover up their noses in the sand. To escape its effects, travellers throw themselves as close as possible to the ground, and wait till it has passed by, which is commonly in a few minutes. As soon as they who have life dare to rise again, they examine how it fares with their companions, by plucking at their arms or legs; for if they are destroyed by the wind, their limbs are absolutely mortified, and will come asunder. It is said of this wind, that if it happens to meet with a shower of rain in its course, and blows across it, it is at once deprived of its noxious quality, and becomes mild and innocent. It is also said, that it was never known to pass the walls of a city \*.

This account of the samiel is extracted from the travels of Mr. Ives over land to the East Indies. Whether this wind is identically the same with that which is described by Mr. Bruce under the name of the simoom, I cannot determine. The facts in both accounts have a very close agreement, and the climate and situation where they occur are not materially different. In the same desert Mr. Bruce observed the astonishing phenomenon of moving pillars of sand †, which are probably the effects of a number

\* See Adams's Lectures, vol. iv. p. 541.

† " So where our wide Numidian wastes extend,  
Sudden th' impetuous hurricanes descend,

Wheat

number of whirlwinds in those torrid regions. As the description of these pillars is in some degree blended with that of the simoom, I shall extract the whole passage. In relating the particulars of his journey across a certain part of the deserts of Africa, Mr. Bruce observes ' We were here at once surprised and terrified by a sight surely one of the most magnificent in the world. In that vast expanse of desert, from west and to north west of us, we saw a number of prodigious pillars of sand at different distances, at times moving with great celerity, at others stalking on with a majestic slowness; at intervals we thought they were coming in a very few minutes to overwhelm us; and small quantities of sand did actually more than once reach us. Again they would retreat so as to be almost out of sight, their tops reaching to the very clouds. There the tops often separated from the bodies; and these, once disjoined, dispersed in the air, and did not appear more. Sometimes they were broken near the middle, as if struck with a large cannon shot. About noon they began to advance with considerable swiftness upon us, the wind being very strong at north. Eleven of them ranged alongside of us about the distance of three miles. The greatest diameter of the largest ap-

Wheel through the air, in circling eddies play,  
Tear up the sands, and sweep whole plains away;  
Th' affrighted traveller, with wild surprise,  
Sees the dry desert all around him rise,  
And, smother'd in the dusty whirlwind, dies."

Addison's Cato.

peared to me at that distance, as if it would measure ten feet. They retired from us with a wind at south east; leaving an impression upon my mind to which I can give no name, though surely one ingredient in it was fear, with a considerable deal of wonder and astonishment. It was in vain to think of flying; the swiftest horse, or fastest sailing ship, could be of no use to carry us out of this danger; and the full persuasion of this rivetted me as if to the spot where I stood, and let the camels gain on me so much in my state of lameness, that it was with some difficulty I could overtake them.'

The same phenomena again occurred in the course of a few days. 'The same appearance of moving pillars of sand presented themselves to us this day, in form and disposition like those we had seen at Waadi Halboub, only they seemed to be more in number, and less in size. They came several times in a direction close upon us; that is, I believe, within less than two miles. They began immediately after sun-rise, like a thick wood, and almost darkened the sun: his rays shining through them for near an hour, gave them an appearance of pillars of fire. Our people now became desperate: the Greeks shrieked out, and said it was the day of judgment. Ismael pronounced it to be hell, and the Tucorories, that the world was on fire. I asked Idris if ever he had before seen such a sight? he said he had often seen them as terrible, though never worse; but what he feared most was that extreme redness in the air, which was a sure presage of the  
coming

coming of the simoom. I begged and intreated Idris that he would not say one word of that in the hearing of the people, for they had already felt it at Imhanfara, in their way from Ras el Feel to Teawa, and again at the Acaba of Gerri, before we came to Chendi, and they were already nearly distracted at the apprehension of finding it here.

At half past four o'clock in the afternoon, we left Waadi Del Aned, our course a little more to the westward than the direction of Syene. The sands which had disappeared yesterday scarcely shewed themselves at all this day, and at a great distance from the horizon. This was, however, a comfort but of short duration. I observed Idris took no part in it, but only warned me and the servants, that, upon the coming of the simoom, we should fall upon our faces, with our mouths upon the earth, so as not to partake of the outward air as long as we could hold our breath. We alighted at six o'clock at a small rock in the sandy ground, without trees or herbage, so that our camels fasted all that night. This place is called Ras el Sheah, or, by the Bishareen, El Mout, which signifies death, a name of bad omen.

On the 16th, at half past ten in the forenoon, we left El Maut, standing in the direction close upon Syene. Our men, if not gay, were, however, in better spirits than I had seen them since we left Gooz. One of our Barbarins had even attempted a song; but Hagi Ismael very gravely reproved him, by telling him, that singing in such a situation was a tempting

of Providence. There is, indeed, nothing more different than active and passive courage. Hagi Ismael would fight, but he had not strength of mind to suffer. At eleven o'clock, while we contemplated with great pleasure the rugged top of Chiggre, to which we were fast approaching, and where we were to solace ourselves with plenty of good water, Idris cried out, with a loud voice, Fall upon your faces, for here is the simoom. I saw from the south east a haze come, in colour like the purple part of the rainbow, but not so compressed or thick. It did not occupy twenty yards in breadth, and was about twelve feet high from the ground. It was a kind of blush upon the air, and it moved very rapidly, for I scarce could turn to fall upon the ground with my head to the northward, when I felt the heat of its current plainly upon my face. We all lay flat on the ground, as if dead, till Idris told us it was blown over. The meteor, or purple haze, which I saw, was indeed passed, but the light air that still blew was of heat to threaten suffocation. For my part, I found distinctly in my breast, that I had imbibed a part of it; nor was I free of an asthmatic sensation till I had been some months in Italy, at the baths of Poretta, near two years afterwards \*.

Whirlwinds and water-spouts have by many philosophers been considered as entirely electrical phenomena, while others have attributed them to a

\* Bruce's Travels. Vol. iv. p. 553, 555.

different.



different cause, and accounted for them upon the principles of hydrostatics: It is possible, however, that there may really be two kinds of water-spouts, the one the effect of the electrical attraction, as described in Book iv. c. 6. and the other caused by a vacuum, or extreme and sudden rarefaction of the air. The whirlwinds at least, which I have observed in this country, were, I am persuaded, of the latter kind; at least whatever was the original cause, the circumagitation or spiral motion of the air must have continued long after every electrical power had ceased to act.

It is well known that even a common fire produces a kind of circulation of the air in a room, but in a different form. It is therefore not difficult to conceive, that when any part of the column of air upon the surface of the earth or water is suddenly rarified, either by electricity or any other cause, a vacuum, at least comparatively to the rest of the air, will immediately take place, and, the circumambient air rushing in at once from every quarter to fill the void, a conflict of winds ensues, and consequently a circular motion, by which light bodies will be taken up and turned round with considerable velocity; this violent rushing of the air on all sides into the vacuum then forms what is commonly called at land a whirlwind.

When this vacuum takes place at sea, from the nature of fluids, the water will rise to a certain height by the pressure of the atmosphere, as in a common pump; but as the vacuum is not quite

perfect, the water will be divided into drops, and as these vacuums are generally caused by heat, it will be rarefied when it reaches the upper regions of the atmosphere, and assume the appearance of a cloud.

Mr. Oliver \*, whose theory I have adopted with little variation, illustrates the phenomenon by a very easy experiment. In a stiff paper card he made a hole just large enough to insert a goose quill; after cutting the quill off square at both ends, he laid the card upon the mouth of a wine glass, filled with water to within a fifth or sixth part of an inch from the lower orifice of the quill; then applying his mouth to the upper part, he drew the air out of the quill, and in one draught of his breath drew in about a spoonful of water; and this he was able to repeat, the quill remaining as before. The water, he adds, did not ascend to his mouth in a stream, as it would have done had the quill reached the water, but broken, and confusedly mixed with the air which ascended with it. The usual phenomena of water-spouts are exactly agreeable to this theory. They appear at a distance like an inverted cone, or the point of a sword, which is owing to the water rising in large drops at the first, and being expanded as it ascends; and a cloud is generally suspended over the body of the phenomenon. The water which is taken up is undoubtedly salt at the first, but by the rarefaction in the superior regions, it un-

\* Philad. Trans. vol. ii.

dergoes a kind of natural distillation, and loses all the heavy saline particles with which it was charged. Water-spouts have been observed at land, of which two very remarkable instances are recorded in the Philosophical Transactions. Other phenomena have been remarked, which can be explained upon these principles only. Accounts have been given of red and yellow rain, of frogs and tadpoles, and even small fishes, having been rained upon the tops of houses. The red and yellow rain was, I apprehend, composed of the blossoms of vegetables, or of insects, taken up by one of these aerial tubes; and the frogs and fishes were probably a part of the contents of some pond, in which the water-spout originated, or over which it might have passed in its perambulation.

The point or cone of the water-spout is generally oblique, depending on the force and direction of the wind which drives it along.

Dr. Perkins, of Boston, whom I had occasion to mention, when treating of hurricanes, in a paper published in the same volume of American Transactions, is disposed to adopt a different theory of water-spouts. Captain Melling informed him, that in a voyage from the West India Islands to Boston, a water-spout came across the stern of the vessel where he then was, a flood of water fell upon him with such violence as almost to beat him down, and the spout immediately passed off with a roaring noise into the sea. The water from the spout, he remarked, was perfectly fresh.

Dr.

Dr. Perkins adds several other instances, on the testimony of mariners, who all affirmed, that *they* saw the water *descend* from the cloud through the water-spout into the sea, contrary to the opinion of Mr. Oliver, that it always ascends.

A whirlwind, therefore, in the opinion of Dr. Perkins, cannot be the cause of a water-spout; ~~nor~~ can both of these phenomena proceed from ~~the~~ same cause. A whirlwind, he supposes to be produced by the ascent of the heated or rarefied air into or through the colder regions of the atmosphere above. Now, Dr. Arbuthnot says, that the rarefaction of the hottest day renders the air but one-tenth lighter than it is in the coldest.

This roaring noise also, as remarked by Captain Melling, does not agree with the theory of the ascent of water in the spout, as it is not very clear why such a noise should accompany the simple ascent of water.

To determine the matter, it is to be wished, that future observers would be careful to remark, 1st. The incipient state of a water-spout, and in particular, whether any cloud is seen hovering over the part in which it commences; and 2dly, whether the conical part seems gradually to descend from the body of the cloud \*.

A tornado seems to partake much of the nature of the two preceding phenomena, but is more vio-

\* Philad. Transf. vol. ii.

lent in its effects. It commences very suddenly, several clouds being previously drawn together, when a spout of wind, proceeding from them, strikes the ground in a round spot of a few rods or perches diameter, in the course of the wind of the day, and proceeds thus half a mile or a mile. The proneness of its descent makes it rebound from the earth, throwing such things as are moveable before it, but some sideways or in a lateral direction from it. A vapour, mist, or rain descends with it, by which the path of it is marked with wet.

The gentleman, who furnishes the above general description, gives an account of one which happened a few years since at Leicester, about fifty miles from Boston, in New England, ' It happened in July, on a hot day, about four o'clock in the afternoon. A few clouds having gathered westward, and coming over head, a sudden motion of their running together in a point being observed, immediately a spout of wind struck the ground at the west end of a house, and immediately carried it away with a negro man in it, who was afterwards found dead in the path of it. Two men and a woman, by the breach of the floor, fell into the cellar; and one man was driven forcibly up into the chimney-corner. These were preserved, though much bruised; they were wet with a vapour or mist, as were the remains of the floor, and the whole path of the spout. This wind raised boards, timbers, &c. A joist was found on one end, driven near  
three

three feet into the ground. The spout probably took it in its elevated state, and drove it forcibly down. The tornado moved with the celerity of a middling wind, and constantly declined in strength till it entirely ceased.'

## C H A P. XII.

OF THE HEAT OF THE ATMOSPHERE AND  
IGNEOUS VAPOURS.

*Objects of Meteorology as a Science.—Partly anticipated.—Temperature.—Heat of the Earth.—Effects of the Sun's Rays on different Mediums.—Difference with respect to Temperature between Land and Water.—Effects of Clouds on the Temperature.—Of Evaporation.—Unusual Cold, how produced in Summer and Winter.—Aqueous Meteors.—Igneous Meteors.—Fire Balls.—Shooting Stars.—Ignes Fatui.*

**M**ETEOROLOGY, in its most extensive sense, would embrace a large scope of science. It includes every thing that concerns our atmosphere, climate, temperature, vapours, fogs, dew, rain, hail, snow, the igneous vapours, as proceeding from inflammable air, and even thunder and lightning, and all those phenomena which are produced by what is termed natural electricity.

The arrangement adopted in these volumes, which was the clearest that suggested itself to my mind, necessarily excludes many of these subjects. The electrical phenomena have been already treated of, and the theory of rain, snow, &c. as adopted by the electrical philosophers, has been briefly explained; and what remains to be said on aqueous meteors will be more properly introduced in the  
book

book which is dedicated to the subject of *water*, and will be better understood when the properties of that fluid are more fully explained.

The phenomena, which present themselves for our immediate consideration, will therefore be those which are, strictly speaking, aerial or atmospherical. The temperature of the atmosphere will therefore, with propriety, be considered, and the igneous meteors with which it is occasionally charged, and of which the air appears not only to be the vehicle but the pabulum.

The variations of temperature which we experience are chiefly produced in the atmosphere, or at no great distance from the surface of the earth. This is evident from a simple and well known fact, that the earth, at a certain depth beneath the surface, always preserves nearly the same temperature, and the degree of heat at those depths generally approaches the mean annual heat of the climate. Even where there is a communication with the external air, the earth, at the depth of 80 or 90 feet, commonly varies but little in its temperature; and where there is no such communication the variation must be still more inconsiderable. Thus the temperature of springs does not vary with the season; and thus the cave of the observatory at Paris, which is about ninety feet below the pavement, preserves the constant temperature of about 53 degrees, never varying above half a degree in the coldest years. Van Swinden has remarked, that the most extreme cold, even exceeding 0 in Fahrenheit's scale, if it  
2 endures



endures for only a few days, penetrates no further than twenty inches, even when the ground is not covered with snow, and not more than ten inches when there is a coat of snow on the surface of the earth.

The earth may, therefore, be considered as the great repository of heat; but when its surface is rapidly cooled, the interior parts experience a diminution of their heat in some measure proportionable, as the heat is in that case drawn off towards the surface. Hence in Switzerland it has been remarked, that the snow generally begins to melt at the bottom; and if the heat of the sun is not strong, the same thing may be observed in the progress of a thaw in this country.

The surface of the earth is capable of receiving a great accession of heat from the sun's rays. But it has been before remarked, that light has not the same effect on a transparent medium, for these mediums afford a free passage to the rays of the sun, which appear to act only as fire, when accumulated and confined within the minutest interstices of bodies. Hence the tops of high mountains are always, even under the equator, covered with snow; and hence at a certain height, which varies in almost every latitude, it freezes during the night in every season, as was stated in a preceding chapter.

Heat is observed to diminish as we ascend into the atmosphere, nearly in an arithmetical proportion. In the vicinity of Paris, lat.  $48^{\circ} 50'$  the temperature of the earth being  $47^{\circ}$ , at the estimated height

height of 11,084 feet, it was found by M. Charles, the aerostatical adventurer, to be at  $21^{\circ}$  or  $11^{\circ}$  below congelation; near Dijon, lat.  $47^{\circ}$  on the 25th of April, the temperature near the earth was  $56^{\circ}$ , but at the height of 10,631 feet, it was found by M. Morveau to be  $26^{\circ}$ ; and Lord Mulgrave, at the bottom of Hacklyt Hill, lat.  $80^{\circ}$ , found the temperature of the lower air  $50^{\circ}$ ; but on the summit of the hill, 1503 feet, only  $42^{\circ}$ .

Water resembles air in being little affected by the passage of the sun's rays; but the bottom of every sea or lake, being opaque, the heat is still capable of being excited and collected there. Between water and earth there is, however, this difference, that land or earth (particularly if dry) receives heat very readily from the rays of the sun, but conducts it through its own substance very slowly to any great depth; whereas water, from its transparency, receives heat from light but slowly; but the heat is diffused through the whole mass with great rapidity. Dr. Hales relates, that in August, 1724, when the air and the surface of the earth were both at 88, a thermometer, placed at only two inches depth in the ground, stood at 85, another at sixteen inches at 70, and another at twenty-four inches at 68. The two last preserved the same temperature day and night to the end of the month, and then only fell to 63. On the 26th of October, a thermometer exposed to the air by the same philosopher, stood at  $35^{\circ} 5$ , but one sunk two inches in the earth was heated to  $43^{\circ} 85$ ,  
another

another sunk sixteen inches reached  $48^{\circ} 8$ , and one at twenty-four inches,  $50^{\circ}$ . He even found, that between the 1st and 2d of November, when the external air was at  $27^{\circ}$ , a thermometer at twenty-four inches depth stood at  $43^{\circ} 8$ ; but from March to September, the following year, the external air was much warmer than the earth at sixteen inches or two feet; but the season was rainy, and the evaporation being considerable, prevented the earth near the surface from being considerably warmed.

From these experiments it appears, that the surface of the earth may be considerably heated, and yet that the heat shall not penetrate to any considerable depth; it appears also, that the earth parts with its heat with difficulty to the air, and will retain its natural temperature, which is between  $40^{\circ}$  and  $50^{\circ}$ , at a very small depth beneath the surface, even when the air is below the freezing point. In water, on the contrary, the heat is not accumulated in a particular part, but is equally diffused through the whole mass, and the temperature, if the surface is extensive, will be more in agreement with that of the atmosphere than with that of the earth. Near Marseilles, Dr. Raymond found the sand frequently heated to  $160^{\circ}$ , but never found the sea hotter than  $77^{\circ}$ , and even this degree of heat it appeared to receive chiefly by its communication with the land, for on the 19th of July, 1765, he found that part of the bay, which was next the land, heated to  $74^{\circ}$ , while the middle was  $72^{\circ}$ , and the entrance

only  $70^{\circ}$ . In winter, he observed the earth cooled down frequently to  $14^{\circ}$  or  $15^{\circ}$ , but the sea never lower than  $44^{\circ}$  or  $45^{\circ}$ .

It is by the temperature of the atmosphere that we always judge when we term the weather cold or hot; but the atmosphere derives the greater part of its heat from its communication with land or water. The rigours, therefore, of the winter's cold are tempered by the heat imparted from the earth itself; yet as the earth parts but slowly with its heat, and as the surface is found to be extremely cool, while the interior parts are heated to the degree of  $40$  or  $50$ , and as the heat of water is more equally diffused, and more readily parted with, it follows that the portion of air, which is incumbent on the sea, will be of a warmer temperature in the extreme cold of winter than that which is incumbent upon the land.

Islands are more temperate than continents, because they participate more of the temperature of the sea. With respect to those countries also, which border on the ocean, those which lie south of the sea, at least in our hemisphere, will be warmer than those which have the sea to the south of them, because the winds which would cool them in winter, if they blew over-land, are tempered by passing over the sea, whereas those which lie north of the sea are cooled in summer by the breezes that issue from it.

Every habitable latitude must enjoy a heat of  $60^{\circ}$  at least for two months in the year, in order

to produce and bring to maturity corn and the other vegetable productions. The quickness with which vegetation proceeds in high latitudes is chiefly owing to the long duration of the sun above the horizon during their summer. Dr. Halley, indeed, has proved, that, abstracting from the intervention of fogs, mists, and mountains of ice, the hottest weather might take place, even under the poles, the duration of the sun's light compensating for the obliquity of its direction.

Among the causes of the changes of weather in these climates, especially with respect to heat or cold, we must account the circumstance of the air being charged with vapour. The air, when cloudy, is capable of receiving and retaining more of the sun's heat, than when clear, for the obvious reason, that a transparent medium permits those rays to pass through it, which are intercepted if the medium is thicker and less pellucid. Hence a cloudy air is frequently found warmer than the earth, on which it is incumbent. The air is also warmed by the condensation of vapour, and hence the origin of hail, which is rain condensed by passing through air which is colder than that which produced it.

A continuance, however, of cloudy or misty weather will intercept the sun's rays from reaching the earth, which will therefore be prevented from receiving its due portion of heat. The winter of the year 1783-4 was unusually severe; and it is to be remarked, that during several of the

summer months which preceded it, where the effect of the sun's rays to heat the earth should have been the greatest, the whole continent of Europe was covered with a kind of fog, supposed to proceed from the smoke of some volcanoes, near Mount Hecla, in Iceland. This fog was of a dry kind, and consequently the sun's rays were incapable of dissipating it; and they were so faint, that in passing through it, when collected in the focus of a burning glass, they would scarcely kindle brown paper\*.

A principal cause of the varieties and changes of temperature, and a most powerful agent in producing cold, is evaporation. On this subject it is remarked, first, that in our climates the evaporation is about four times as great between the vernal and autumnal equinox as in the rest of the year. 2dly. Other circumstances equal, it is increased in proportion to the difference between the temperature of the air and the evaporating surface; it is consequently least when they are nearly of equal temperature. The former part of this proposition must be understood with some restriction; for if the air is more than  $15^{\circ}$  colder than the evaporating surface, there is seldom any evaporation at all, and the air will more frequently, in that case, deposit moisture than receive it. 3dly. The degree of cold produced by evaporation is much greater when the air is warmer than the evaporat-

\* See Dr. Franklin's Meteorological Conjectures.

ing surface, than when the latter is the warmer of the two; for in the first case the dilation of the vapour is increased, and in the second, it is checked. The more vapour is dilated, the more fire or heat it absorbs; and hence it is coldest in an exhausted receiver, where it absorbs most. Hence warm winds, as the harmattan, sirocco, &c. are more desiccatory than cold winds. 5thly. Evaporation is always increased greatly by a current of air flowing over the evaporating surface. Hence a calm day is always better than one in which there is a strong wind\*.

From these facts, and from what was previously remarked on the subject of evaporation in the second book, it is plain, that tracts of land which are covered with trees or luxuriant vegetables are much colder than those where there is a less surface of vegetable matter, such grounds emitting one *third* more vapour, according to some experiments of Mr. Williams, than the same space would if actually covered with water†. Hence too, a reason will evidently be found for that amazing change of climate which a country undergoes by being cleared and cultivated. America is not the same country at present, either with respect to temperature or salubrity, as when it was covered with woods.

From the whole of what has been stated, it will follow, that a wet summer will generally be suc-

\* Kirwan on Climate, c. i.

† Philad. Transf. vol. ii. p. 150.

ceeded by a severe winter, because the cloudiness of the season will prevent the earth from receiving a due portion of heat, and because the increased evaporation will contribute to lessen the quantity already lodged there. Much will, however, depend upon other circumstances, and particularly upon the course of the wind.

Unusual cold in summer is produced—1st. From the long continuance of easterly or northerly winds.

2dly. From frequent and heavy rains, which are followed by a considerable evaporation.

3dly. From a long continuance of cloudy weather, which prevents the earth from receiving a proper portion of heat from the sun.

Unusual cold in winter commonly happens—

1st. From unusual cold or wet in the preceding summer. In January 1709, the weather was uncommonly cold, and it was remarked, that in the preceding June the thermometer was near the freezing point, and the rain considerable\*.

2dly. From the immediate effect of heavy rains, followed by easterly or northern winds. This state of things produces cold in any season from the increased evaporation.

3dly. From westerly or southerly currents in the upper regions of the atmosphere, while east or north winds prevail nearer the surface of the earth.

\* Derham's Physic. Theol. 1. i. c. 3.



4thly. From the arrival of Siberian or North American winds. It has been calculated, that westerly winds may arrive in a few days from America; and if the ocean has been previously cooled by northern gales, even these will seem cold to us. The Siberian winds will, if they originate from a lower latitude, seem to us to come from the south-east; and if they originate in a higher latitude, they will appear north-east, because they will be deflected to the south.

5thly. From the descent of a superior stratum of the atmosphere. This happens when a cold wind in the upper regions passes over a country where the lower strata of the atmosphere are specifically lighter.—Hence a low state of the barometer generally precedes extraordinary cold which is produced from this cause.\*.

On the state of the atmosphere with respect to heat and cold, and still more on the degree of evaporation, all the phenomena of the aqueous meteors of rain, hail, snow, &c. will be found to depend; but these will be treated of with more propriety in another part of these volumes. The igneous vapours are also connected with the same causes, and are in a considerable degree the effects of evaporation; but their materials are different, as well as their effects, though, from their evanescent nature, they are scarcely at present sufficiently understood.

\* Kirwan on Climate, c. 12.

As the phenomena which are strictly electrical have been already treated of, the only meteors of the igneous kind, which remain to be considered, may be reduced to three classes, viz. fire-balls, falling-stars, and ignes fatui.

It has been already stated, that the atmosphere is the general reservoir of those particles which are exhaled from every body which is volatile, or subject to evaporation. In speaking of the fire damp in mines it has been shewn, that inflammable air will rise in large quantities, and to a considerable height in the atmosphere. There are also some phosphoric matters, which will also occasionally be rendered volatile, and these particles are supplied in great abundance from all putrescent substances, whether animal or vegetable. It has been shewn, that hydrogen or inflammable air readily combines with sulphur, and forms what is called hepatic gas; it will afterwards appear also, that it will combine with phosphorus, and the phosphorated hydrogen gas thus formed is remarkable for the property of spontaneously inflaming when it comes into contact with atmospherical air. Thus we are furnished with sufficient materials for the formation of all the different appearances that have just been enumerated; and though the matter of the meteors themselves has, for the reason assigned, never been chemically analyzed, yet from analogy it is not difficult to judge of their nature and properties.

Those phenomena, which are classed together under the general appellation of fire-balls, were divided

vided: by the ancients into several species, according to the external form or appearance which they assumed. They were also regarded by them in a much more formidable light than they are by us, as the certain prognostics of great and awful events in the moral and political world. Even the philosophic Cicero speaks of the “*ab occidente faces*,” as the certain harbingers or indications of those bloody scenes which in his time convulsed and desolated the Roman commonwealth.

Under the general name of comets, Pliny enumerates a variety of these phenomena. If the fire commences at one extremity of the meteor, and burns by degrees, he terms it, from its form and appearance, a *lamp*, or *torcb*; if an extended mass of fire passes longitudinally through the atmosphere, he calls it a *dart*; and if its length and magnitude are considerable, and it maintains its station for any space of time, it is a *beam*; if the clouds seem to part, and emit a quantity of fire, he terms it a *chasm*\*; but this last appears to be, strictly speaking, an electrical phenomenon, indeed only a strong and vivid flash of lightning.

Several instances of these meteors are recorded by the same author. During the spectacle of gladiators exhibited by Germanicus, one of them passed rapidly by the faces of the spectators at noon-day. A meteor of that species which he calls a beam, he

\* Lampades, faces, bolides, trabes, and chasma cœli. See Plin. Nat. Hist. l. ii. c. 25, 26.

adds, was seen when the Lacedæmonians were defeated at sea, in that memorable engagement which lost them the empire of the sea\*. He also mentions a sanguineous kind of meteor, a flame as red as blood, which fell from heaven about the 107th Olympiad, when Philip of Macedon was concerting his wicked plan for enslaving the republics of Greece †. He relates, that when he was himself on the watch during the night in the Roman camp, he was a spectator of a similar appearance—a number of resplendent lights fixed upon the palisades of the camp, similar, he says, to those which mariners speak of as attaching themselves to the masts and yards of a ship ‡.

In tropical climates these meteors are more common and more stupendous than in these more temperate regions. ‘As I was riding in Jamaica,’ says Mr. Barbham, ‘one morning from my habitation, situated about three miles north-west from St. Jago de la Vega, I saw a ball of fire, appearing to me about the bigness of a bomb, swiftly falling down with a great blaze. At first I thought it fell into the town; but when I came nearer, I saw many people gathered together, a little to the southward, in the Savannah, to whom I rode up, to inquire the cause of their meeting: they were admiring, as I found, the ground’s being strangely

\* Plin. Nat. Hist. l. ii. c. 25, 26.

† Ib. c. 27.

‡ Ib. c. 37.

broken up and ploughed by a ball of fire; which, as they said, fell down there. I observed there were many holes in the ground; one in the middle, of the bigness of a man's head, and five or six smaller round about it, of the bigness of one's fist, and so deep as not to be fathomed by such implements as were at hand. It was observed, also, that all the green herbage was burnt up near the holes; and there continued a strong smell of sulphur near the place for some time after.'

Ulloa gives an account of one of a similar kind at Quito\*. 'About nine at night,' says he, 'a globe of fire appeared to rise from the side of the mountain Pichinca, and so large, that it spread a light over all the part of the city facing that mountain. The house where I lodged looking that way, I was surprised with an extraordinary light, darting through the crevices of the window-shutters. On this appearance, and the bustle of the people in the street, I hastened to the window, and came time enough to see it, in the middle of its career, which continued from west to south, till I lost sight of it, being intercepted by a mountain that lay between me and it. It was round, and its apparent diameter about a foot. I observed it to rise from the sides of Pichinca, although, to judge from its course, it was behind that mountain where this congeries of inflammable matter was kindled. In the first half of its visible course it emitted a prodigious

\* Ulloa, vol. i. p. 41.

gious effulgence, then it began gradually to grow dim; so that, upon its disappearing behind the intervening mountain, its light was very faint.

‘ Meteors of this kind are very frequently seen between the tropics; but they sometimes, also, visit the more temperate regions of Europe. We have the description of a very extraordinary one, given us by Montanari, that serves to shew to what great heights, in our atmosphere, these vapours are found to ascend. In the year 1676, a great globe of fire was seen at Bononia, in Italy, about three quarters of an hour after sun-set. It passed westward, with a most rapid course, and at the rate of not less than a hundred and sixty miles in a minute, which is much swifter than the force of a cannon-ball, and at last stood over the Adriatic sea. In its course it crossed over all Italy; and, by computation, it could not have been less than thirty-eight miles above the surface of the earth. In the whole line of its course, wherever it approached, the inhabitants below could distinctly hear it, with a hissing noise, resembling that of a fire-work. Having passed away to sea, towards Corfica, it was heard at last to go off with a most violent explosion, much louder than that of a cannon; and, immediately after, another noise was heard, like the rattling of a great cart upon a stony pavement, which was, probably, nothing more than the echo of the former sound. Its magnitude, when at Bononia, appeared twice as long as the moon one way, and as broad the other; so that, considering its height,  
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it could not have been less than a mile long and half a mile broad. From the height at which this was seen, and there being no volcano on that quarter of the world from whence it came, it is more than probable that this terrible globe was kindled on some part of the contrary side of the globe, in those regions of vapours which we have been just describing, and thus, rising above the air, and passing in a course opposite to that of the earth's motion, in this manner it acquired its amazing rapidity \*.

Two of these meteors appeared in this country in the year 1783, of which a most particular and truly philosophical account, and ingenious solution, by Dr. Blagden, is published in the Philosophical Transactions of the following year; and as this account will apply to many phenomena of the kind, I cannot take any better method to elucidate this part of the subject, than by presenting my readers with a short abstract of this very curious and learned memoir.

The first of the two meteors in question was seen on the 18th of August, and was, in appearance, a luminous ball, which rose in the N. N. W. nearly round; it, however, soon became elliptical, and gradually assumed a tail as it ascended, and, in a certain part of its course, seemed to undergo a remarkable change, compared to bursting; after which it proceeded no longer as an entire mass, but was apparently divided into a cluster of balls of different magnitudes, and all carrying or leaving a

\* Goldsmith's Hist. Earth, Vol. I. p. 382.

train behind, till, having passed the east, and verging considerably to the south, it gradually descended, and was lost out of sight. The time of its appearance was about sixteen minutes past nine in the evening, and it was visible about half a minute. It was seen in all parts of Great Britain, at Paris, at Nuits in Burgundy, and even at Rome, and is supposed to have described a tract of one thousand miles at least over the surface of the earth. It appears to have burst and re-united several times; and the first bursting of it which was noticed seems to have been somewhere over Lincolnshire, perhaps near the commencement of the fens. This change in the meteor corresponds with the period in which it suffered a deviation from its course. If, indeed, the explosion was any kind of effort, we cannot wonder that the body should be diverted by it from its direct line; and, on the other hand, it seems equally probable, that if it was forced by any cause to change its direction, the consequence would naturally be a separation of its parts.

The illumination of these meteors is often so great as totally to obliterate the stars, to make the moon look dull, and even to affect the spectators like the sun itself. When this meteor was observed at Brussels, the moon appeared quite red, but when it was passed, recovered its natural light. This effect, the Doctor remarks, must have depended on the contrast of colour, and shews how large a proportion of the blue rays enters into that light which could even make the *silver* moon appear to have an excess of  
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of red. The body of the fire-ball, even before it burst, did not appear of an uniform brightness, but consisted of lucid and dull parts, which were constantly changing their respective positions, so that the whole effect was to some eyes like an internal agitation or boiling of the matter. By the best accounts that could be procured concerning the height of the meteor, it seems to have varied from fifty-five to sixty miles. In these two last particulars it seems to have wonderfully corresponded with some other phenomena of the same kind.

A report was heard some time after the meteor disappeared, and this report was loudest in Lincolnshire and the adjacent parts, and again in the eastern parts of Kent; the report we may therefore suppose to be the effect of the two explosions of the body; first over Lincolnshire, and afterwards when it entered the continent; a hissing sound was said also to have accompanied the progress of the meteor. Judging from the height of the meteor, its bulk is conjectured to have been not less than half a mile in diameter; and when we consider this bulk, its velocity cannot fail to astonish us, which is supposed to be at the rate of more than forty miles in a second.

The other meteor, which appeared on the 4th of October, at forty-three minutes past six in the evening, was much smaller than the former, and of a much shorter duration. It was first perceived to the northward, as a stream of fire, like the common shooting stars, but large; but presently burst out  
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into that intensely bright bluish flame, which is peculiar to such meteors. It left behind it a dusky red streak of fire, and, except this, had no tail, but was nearly globular. After moving not less than ten degrees in this bright state, it became suddenly extinct without any explosion. The height of the meteor must have been between forty and fifty miles; and its duration was not more than three seconds.

The Doctor is of opinion, that the general cause of these phenomena is electricity, which opinion he grounds upon the following circumstances:—1st, The velocity of these meteors, in which they correspond with no other body in nature but the electrical fluid. 2dly, The electrical phenomena attending meteors, the lambent flames, and the sparks proceeding from them, which have sometimes damaged ships and houses in the manner of lightning; and, added to these, the hissing sound, resembling that of electricity passing from a conductor. As a third argument in favour of this hypothesis, the Doctor remarks the connection of meteors with the northern lights. Instances are recorded, where northern lights have been seen to join, and form luminous bails, darting about with great velocity, and even leaving a train-like fire-balls. The aurora borealis appears to occupy as high, if not a higher, region above the surface of the earth, as may be concluded from the very distant countries to which it has been visible at the same time. 4thly, The most remarkable analogy, the Doctor thinks,  
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is the course of at least all the larger meteors, which seems to be constantly from or towards the north or north-west quarter of the heavens. Of above forty different fire-balls described in the Philosophical Transactions, twenty are so described, that it is certain their course was in that direction; only three or four seem to have moved the contrary way; and with respect to the remainder, it is left doubtful, from the imperfect state of the relations.

Notwithstanding the Doctor's ingenious arguments, I cannot, on my own part, subscribe to the opinion, that these phenomena are altogether electrical. The duration of the fire-ball, the unequal consistency of the mass, and several other points in the narration, seem to indicate that its materials were of a less rare and evanescent nature than the electric fire. The union of phosphorus and hydrogen in the atmosphere, will sufficiently account for the inflammation of these masses of volatile matter, and their colour will depend on the nature of the composition, as is plain from what has been said upon the subject of the fire-works produced from inflammable air \*.

One instance more of this kind of phenomena I shall beg leave to mention, particularly as it differs in many respects from the preceding; and from its duration, and the strong smell which attended the explosion, it seems not to have been the effect of electricity.

\* See Chap. V.

On board the *Montague*, under the command of Admiral Chambers, in lat.  $42^{\circ} 48'$ . long.  $9^{\circ} 3'$ . on the 4th of November 1749, about ten minutes before twelve, as the author, Mr. Chalmers, was taking an observation, one of the quarter-masters desired he would look to the windward. On directing his eye that way, he observed a large ball of blue fire about three miles distance from them; they immediately lowered the topsails, but it came so fast upon them, that before they could raise the main-tack, they observed the ball rise almost perpendicularly, and not above forty or fifty yards from the main chains, when it went off with an explosion as great as if hundreds of cannon had been discharged at the same time, leaving behind it a strong sulphureous smell. By this explosion the main-top-mast was shattered in pieces, and the main-mast sent quite down to the keel. Five men were knocked down, and one of them was greatly bruised, and some other damage of less importance was done to the ship. Just before the explosion, the ball seemed to be of the size of a large millstone.

The shooting or falling star is a common phenomenon, but though so frequently observed, the great distance, and the transient nature of these meteors, added to the entire consumption of their materials \*, have

\* It is a vulgar notion, that the small masses of white jelly, which are sometimes found in the fields, are produced from the falling stars, and it is called star jelly. This jelly, however, is  
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have hitherto frustrated every attempt to ascertain their cause. It is, however, reasonable to suppose, that they are intrinsically the same with the larger meteors, as in most of their properties they perfectly correspond with them. If the larger meteors are formed from any mixture or combination of inflammable air with phosphorus, or any other substance, the shooting stars are probably the same. If, on the contrary, the larger meteors are electrical, there is equal reason for supposing the smaller ones to proceed from the same cause. Some philosophers, indeed, represent both as masses of electricity, at so great a distance that their angular velocity is not sufficient to prevent the eye from discerning their shape. There are, however, three reasons which operate against this hypothesis. 1st, The height of these meteors is frequently above that to which clouds ascend, and clouds are the common atmospheric conductors of electricity. 2dly, They do not proceed from a cloud, as flashes of lightning uniformly do. And, 3dly, There is no noise resembling that of thunder at their first emission or appearance; the noise in the large meteors only takes place when the mass separates or goes off like a sky-rocket, and in this case the effect is similar to that of gunpowder, or any discharging body.

Concerning the nature and composition of the *ignis fatuus*, or will-o'-the-wisp, there is less dispute;

the excrement of the heron, bittern, or some animal of the crane kind, which feed on aquatic animals, and have peculiar organs of digestion.

the generality of philosophers being agreed, that it is caused by some volatile vapour of the phosphoric kind, probably the phosphoric hydrogen gas. The light from putrescent substances\*, particularly putrid fish, and those sparks emitted from the sea, or sea-water when agitated in the dark, correspond in appearance with this meteor. Sir Isaac Newton defines the *ignis fatuus* to be "a vapour shining without heat;" and it is usually visible in damp places, about dunghills, burying grounds, and other situations, which are likely to abound with phosphoric matter.

A remarkable *ignis fatuus* was observed by Mr. Derham, in some boggy ground, between two rocky hills. He was so fortunate as to be able to approach it within two or three yards. It moved with a brisk and desultory motion about a dead thistle, till a slight agitation of the air, occasioned, as he supposed, by his near approach to it, occasioned it to jump to another place; and as he approached, it kept flying before him. He was near enough to satisfy himself, that it could not be the shining of glow-worms or other insects—it was one uniform body of light.

M. Beccaria mentions two of these luminous appearances, which were frequently observed in the neighbourhood of Bologna, and which emitted a light equal to that of an ordinary faggot. Their motions were unequal, sometimes rising, and some-

\* This subject will be more amply treated of in the succeeding Book, under the title Phosphorus, Book VIII.

times sinking towards the earth ; sometimes totally disappearing, though in general they continued hovering about six feet from the ground. They differed in size and figure ; and, indeed, the form of each was fluctuating, sometimes floating like waves, and dropping sparks of fire. He was assured there was not a dark night in the whole year in which they did not appear ; nor was their appearance at all affected by the weather, whether cold or hot, snow or rain. They have been known to change their colour from red to yellow ; and generally grew fainter as any person approached, vanishing entirely when the observer came very near to them, and appearing again at some distance.

Dr. Shaw also describes a singular *ignis fatuus*, which he saw in the Holy Land. It was sometimes globular, or in the form of the flame of a candle ; and immediately afterwards spread itself so much, as to involve the whole company in a pale inoffensive light, and then was observed to contract itself again, and suddenly disappear. In less than a minute, however, it would become visible as before, and run along from one place to another ; or would expand itself over more than three acres of the adjacent mountains. The atmosphere at this time, he adds, was thick and hazy.

In a superstitious age we cannot wonder that these phenomena have all been attributed to supernatural agency ; it is one of the noblest purposes of philosophy, to release the mind from the bondage of

imaginary terrors; and by explaining the modes in which the Divine Providence disposes the different powers of nature, to elevate our thoughts to the one first cause; to teach us to see "God in all, and all in God."



## CHAP. XIII,

OF THE PROGNOSTICS OF THE  
WEATHER,

*Imperfect State of this Branch of Science.—Prognostics of Weather from the previous State of the Season.—From the Undulations of the Atmosphere.—From the Barometer.—From Fogs.—From Clouds.—From Prospects.—From the Dew.—From the Sky.—From the Moon.—From the Wind.—Remarks on Water and Wood.*

**A** METHODOICAL arrangement of meteorological phenomena, by which more certain prognostics of the weather might be procured, is a great desideratum in the scale of useful knowledge. That philosophers have already a considerable acquaintance with the nature of heat, water, and air, their numerous and ingenious experiments sufficiently prove; but when these three ingredients of nature are in a compound state floating round our globe, and producing all those various agitations and combinations, known under the general denomination of weather, then their knowledge seems to be without system, without certainty, and contrary to the very end of true philosophy, almost without utility.

utility. From the combination of air and water with heat, from their circulation and their decomposition, arises all that variety of weather of which the atmosphere of all countries, and particularly that of islands, is so susceptible. It is well known, that water exhales from the surface of the earth in the form of a rare, invisible, expanded vapour, and that after it has been dispersed in the air, and suspended in it for some time in that state, it is afterwards condensed into mists and clouds, and afterwards, when collected into drops, it descends in rain, hail, or snow, to the earth whence it originally proceeded, to be there re-evaporated and circulated again through the atmosphere.

The atmosphere itself is influenced and modified by the variations of its density; by its humidity; by the precipitation of the aqueous particles into rain; by the wind; by the power of electricity; and by the agency of heat and cold, as remarked in the preceding chapter.

Though the science of predicting the weather is at present vague and imperfect; because it is but lately that accurate observations have been made on the changes of the weather, yet from what we may collect from the works of De Luc, De Saussure, Marshall, and Kirwan, we are authorized to expect some success in those inquiries. But it can hardly be supposed that their observations, in the present state of science, will be sufficient to form a perfect theory, till seconded by those of succeeding times. For this  
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salutary end it will be necessary to make as many observations on the different signs of the weather as possible, since it is only by their combination and concurrence, that uncertainty can be removed.

The principal means of predicting the changes of weather, and particularly with respect to rain or drought, may be reduced to seven, viz. 1st. From the preceding state of the weather. 2d. From the undulations of the atmosphere. 3d. From the barometer. 4th. From the appearance of the clouds. 5th. From the colour of the sky. 6th. From the wind. 7th. From the moon.

I. As the causes of every change of weather must have preceded for some time the effect, it is in general by an attention to its previous state, that we are enabled to form the most accurate judgment of what weather is to be in future expected; from a series of observations made from 1677 to 1789, Mr. Kirwan lays down the following rules or principles.

1st. When there has been no storm before or after the vernal equinox, the ensuing summer is generally dry, at least five times in six.

2d. When a storm happens from an easterly point either on the 19th, 20th, or 21st of March, the succeeding summer is dry, four times in five.

3d. When a storm arises on the 25th, 26th, or 27th, of March, and not before, in any point, the succeeding summer is generally dry, four times in five.

4th.

4th. If there should be a storm at S. W. or W. S. W. on the 19th, 20th, or 22d, the succeeding summer is generally *wet*, five times in six.

Mr. Kirwan adds, that it rains less in March than in November, in the proportion of seven to twelve. It generally rains less in April than in October, in the proportion of one to two; less in May than September, in the proportion of three to four. When it rains plentifully in May, it generally rains but little in September; and the contrary. A week is accounted wet when it contains four wet days, or more; a month, when it contains three wet weeks; and a season, or quarter of a year, when it contains two wet months. He terms that a *wet* day in which rain falls to the amount of one pound troy, in the space of a square foot.

In any given year, the probability of a *dry* spring is in the proportion of twenty-two to six wet, and thirteen variable. Of a *wet* summer it is twenty to sixteen dry, and five variable. Of a variable autumn, nineteen to eleven of wet or dry. That is, out of forty-one years the spring in twenty-two will be dry, &c.; and so in proportion\*.

II. Among the various means of prognosticating the weather, remarked by the late Mr. Adams †, one of the most important, in his opinion, seems to be that undulating motion, or diurnal tumult in the air, which is kept up by the heat of the sun. The

\* Mem. Royal Irish Acad. Vol. v.

† Dissertation on the Barometer.

humidity raised from the earth by the heat of the sun, is sustained in the atmosphere by its heat, and the agitation of the air. Though this motion is not always visible to the naked eye, yet by the help of a good telescope it becomes eminently conspicuous; every object appears to be in violent agitation, and the boundary line of the sensible horizon, which would otherwise be clear and well defined, is waved like a field of corn agitated by the wind, or the surface of the sea in a fresh gale. While these undulations continue in the air, the vapours remain there; but when the sun departs, and they subside, these aqueous particles become condensed, and descend to the ground during the night, and in the morning assume the appearance of dew.

III. The greatest acquisition, perhaps, that ever was made to natural philosophy, with respect to ascertaining the changes of the weather, was the discovery of the Barometer. The nature and uses of this instrument have been previously described\*. It is evident, that when the mercury rises in the tube, the pressure, weight, or density of the air must be augmented; but the relation that exists between this pressure and the change of weather, which does not take place sometimes till ten or twelve hours afterwards, still remains to be explained.

The pressure of the air upon the reservoir of the barometer proceeds in general from its weight, and sometimes from its elasticity. It has been proved,

\* See this Book, Chap. IX.

that these two properties of air sometimes vary, and, consequently, the pressure which they produce. Whenever the air dissolves a great quantity of water, its specific gravity is increased; the column of air which rests upon the reservoir of the barometer becomes heavier, and the mercury rises. If the solution is not perfect, the transparency of the air will be disturbed; hence a kind of mist will be produced, which will generally cause the mercury in the barometer to rise; but if the solution is perfect, the transparency of the air will be complete, and fine weather return, as the mercury in the barometer predicted by its ascent. While certain causes determine this water, which is held in solution, to descend into the lower region of the atmosphere, before it is sufficiently condensed to be regularly formed into rain, there is another part of it which will have previously arrived at the surface of the earth. As a proof of this, it is observable, that when the weather is about to change to rain, all bodies which are impenetrable to water, such as bars of iron, hard stones, &c. are found to be moist or wet. The column of air which presses upon the reservoir of the barometer, will become, therefore, lighter by the loss of that portion of water already arrived at the earth; and the barometer will descend, and predict the rain, which will come in a short time after, being formed by the remainder of the water, which will then have had time to be formed into regular drops \*.

It must be confessed, that there are some appearances which seem to contradict this explanation.

\* Briffon. Vol. i.

It sometimes happens, that the barometer rises even during rain, while the air discharges itself of the water which it held in solution : it also happens frequently, especially in the winter, that, during whole months, every time that the mercury rises in the barometer, rain continues to fall; and every time that it descends, fine weather returns. Still this may be reconciled to what has been stated; for as (as has been already observed) it is the great quantity of water dissolved in the air which augments its weight, if, therefore, during rain, a new solution of water should by any means be effected in greater abundance than the quantity which falls (and this we know may happen from various causes) the barometer will rise. If the water so dissolved remains in the lower region, this rise of the barometer will predict a fresh fall of rain, which often happens in such cases. In short, if the air dissolves a great quantity of water, and at the same time cold, or some other cause, should impede that water from dissolving perfectly, and rising to a great height, it will augment the weight of the air in a proportionate degree, and will cause the barometer to rise; and in the mean time it will be ready to be collected into drops, and formed into rain, which will soon after take place. While this rain continues to fall, if there is no new solution effected, the air will become lighter; the barometer will fall; and, notwithstanding that, it will predict fine weather, which, according to this rule, ought to happen. That kind of relation which appears to subsist between the  
weight

weight of air and the change of weather, according to circumstances, may be accounted for, therefore, in this manner. Fine weather may happen, notwithstanding the diminution of the weight of air, when some other elastic fluid, lighter than it, becomes intermixed with it, without taking away the transparency. In short, the elasticity of air, the force of which may vary from different causes, will still contribute to vary its pressure. This elasticity acts sometimes in conjunction with the weight, so as to increase the effect of it; at other times it acts in a contrary way, and may also diminish, or even counterbalance, the effect of the augmentation of weight. It follows, then, that fine or bad weather may continue, however high the mercury may be in the barometer; and still this does not weaken the explanation which has before been given of this fact.

Observation, however, in these cases is always preferable to theory; and from long and attentive observation, and from a careful inspection of those of other philosophers, Mr. Adams was enabled to lay down the following principles in his useful treatise on this instrument.

1. It generally happens, that, when the mercury in the tube falls, the air being lighter, it will deposit its vapour, and produce rain: but when it rises, the air being heavier, the vapours will be supported, and fine weather is the usual consequence.

2. When the mercury falls in frosty weather, either snow or a thaw may be expected; but if it  
rises



**rises** in the winter with a north or east wind, it generally forebodes a frost.

3. It is necessary to attend to the progress of the rise and fall; thus, if it sinks slowly, the rain may be expected to be of some continuance. In the same manner, when the mercury rises gradually, we may be inclined to believe, that the fine weather will be lasting.

4. When the barometer is fluctuating, rising and falling suddenly, the weather may be expected to be like it, changeable.

5. When it falls very low, there will be much rain.

6. But if its fall is low and sudden, a high wind frequently follows.

7. When an extraordinary fall of the mercury happens, without any remarkable change near at hand, there is some probability of a storm at a distance.

8. The barometer will descend sometimes as an indication of wind only; nor is its rise always a certain sign of fair weather, particularly if the wind is to the north or the east.

9. A north-east wind generally causes the barometer in England to rise, and it is generally lowest with a south-west wind.

If the air in foggy weather becomes hotter by the action of the sun alone, the fog generally dissipates, and the air remains serene; but if the barometer falls, and the change of temperature is from a south or south-west wind, the fog rises and forms into clouds, and its ascent is generally a sign of rain.

“ We

“We have,” says Mr. Adams, “at present certain data from observations, whereby certain conclusions may be formed relative to fogs, and the connection with rain.”

In winter, when the cold decreases suddenly, rain may be expected; but in summer, a sudden increase of heat forebodes rain.

IV. Several prognostic signs of the weather may be collected from the various appearances of the clouds; when they appear to dissolve suddenly into air, and become invisible, it may be considered as a strong indication of fair weather; but, on the contrary, when they seem to form themselves into masses from the surrounding air, and to increase in density and magnitude, rain may reasonably be predicted.

Upon the approach of heavy rain every cloud rises larger than the preceding one, especially so when a thunder-storm is near, when small fragments of clouds collect, and in a little time cover the whole face of the sky. Fishermen, by this rule, frequently prognosticate a storm, from a small point of a cloud appearing on the visible horizon at sea.

When the clouds appear like fleeces, deep and dense towards the middle, and white at the edges, with a bright blue sky about them, either heavy showers of rain, hail, or snow, may be expected.

Mr. Jones, in his philosophical disquisitions, says, that he predicted a high wind forty hours before it began, from the complexion of a single cloud, with white edges, and dark diverging lines from it; after

this

this appearance there was a great storm, which lasted for two days and two nights.

When the clouds, as they come forward, appear to diverge from a point in the horizon, a wind may be predicted, either from that or the opposite quarter.

When the sky is covered with clouds above, and there are small black fragments of clouds, like smoke, flying underneath, rain is generally near, and frequently lasting.

The most certain sign of rain is two different currents of clouds, especially if the lower current flies fast before the wind; when two such currents appear in hot weather, they forebode a thunder-storm.

The inhabitants of the Alps, when distant objects appear distinct and well defined, and when the sky appears of a deep blue, suppose it a decisive sign of rain, though no other sign of it may appear. The blue colour of the sky in any country is certainly occasioned by a quantity of vapour equally diffused through the air at the time.

Mr. Adams observes of the dew, that, when it appears plentifully upon the grass after a fair day, another fair day may be expected; but if after such a fair day there is no dew upon the ground; and no wind stirring, it is a sign that the vapours ascend, and that there will be an accumulation above, which must terminate in rain. When the dew, or hoar frost, abounds at an unusual season, and the barometer is low, it is in general a sign of rain.

V. As the sky indicates the state of the vapours in the atmosphere, its colour may be considered as an index to the weather.

When the vapours, which appear red in the evening, are dispersed, the sky in the morning is general becomes clear; but when they continue to float in the atmosphere, the morning sky becomes red also; and rain frequently follows.

When a lowering redness spreads far upwards from the horizon, whether in the morning or evening, it is succeeded frequently by either rain or wind, sometimes by both.

When a redness in the sky extends towards the zenith in the evening, the wind may be expected to proceed from the west, or south-west, accompanied with rain in considerable quantity. Perhaps one of the most certain signs of fine weather is the loftiness of the canopy of the sky.

As the rays of light which pass from the sun, moon, or stars, to the earth, are certainly affected in their colour by the state of the vapours through which they pass, those colours may be considered as indications of the quantity and nature of those vapours.

When the clouds in the east, about sun-rise, appear of a gay orange colour, it is generally, and not improperly, supposed to be a sign of rain.

VI. The first of Roman poets, and not the last of natural philosophers, Virgil, observes, that a pale moon is a sign of rain; that a red one forebodes wind;

wind; and that when she wears her own natural whiteness, with a serene sky, it is a sign of fair weather.

Mr. Jones, in his physiological disquisitions, says, that when it rains during a moon, the following change will probably produce clear weather for a few days, and then a continuation of rain; but on the contrary, when it has been fair throughout, and it rains at the change, the fair weather will probably be restored about the fourth or fifth day of the moon, and continue as before. This gentleman adds considerable weight to this observation, by asserting, that he has made hay after these prognostics for twenty years, without having once had the mortification to see it damaged by rain. I must, however, confess, that the reason of the fact is not clear to my mind; and I therefore give it solely upon his authority, and recommend it to future observers to confute or confirm it by accurate observations.

VII. A whistling, howling wind has been generally esteemed almost an infallible sign of rain.

Mr. Adams, in the dissertation which has been quoted, has presented us with some useful observations on warm and cold weather. Living vegetables, says he, have a considerable effect in altering climates and affecting the weather. Woody countries are much colder than those that are open and cultivated. As a proof of this hypothesis, Guiana is commonly adduced, of which only a part has been cleared from wood since the beginning of this cen-

tury; the heat in that part is already become excessive; whereas, in the woody parts of the same country the inhabitants are obliged to light a fire every night.

It is also justly observed, that water abounds most in woody countries; that the purest springs are generally found beneath the friendly shelter of a grove; and that in proportion as the woodlands in any country are cleared, the watercourses are diminished.

Hence may be inferred the necessity of preserving trees about those places whence water-springs discharge their currents, if it is an object to preserve them; and also of improving small springs, by planting trees around them, and especially oaks.

And hence, also, it is a fair conclusion, that in this climate, where the cold certainly predominates, woody situations cannot be wholesome; and that, adjacent to houses especially, the land should be laid open.

## CHAP. XIV.

## AEROSTATION.

*History of Aeroſtation.—Discovery of Air Balloons by M. M. Montgolfier.—First Balloon exhibited at Annonay.—Balloon filled with inflammable Air exhibited at Paris.—Pilatre de Rozier ascends in a Balloon.—First Balloon exhibited in England.—Ascent of M. Lunardi.—Voyage of M. Blanchard and Dr. Jefferies across the Channel.—Unfortunate Cataſtrophe of M. M. de Rozier and Romain.—Mr. Baldwin's Deſcription of the Proſpect from a Balloon.—Principles of Aeroſtation.—Modes of filling Balloons.—Uſe to which they have been applied.*

**W**HEN the principles of natural philoſophy are confined to theory only, they may amuſe and inſtruct the inquiring few, without exciting either the curioſity or admiration of the multitude; but when thoſe theories are reduced to practice, and illuſtrated by experiments, it becomes then more generally intereſting, and attracts the attention of the moſt uninformed minds. Perhaps the principles upon which the air balloons are conſtructed might be among the amuſing ſpeculations of a Boyle or of a Newton, but the actual exhibition of thoſe aerial machines was reſerved to awake the curioſity, and excite the aſtoniſhment, of the preſent age\*.

Mr.

\* Boyle and Newton were certainly ſo far acquainted with the general properties of air, as to obſerve, that ſmoke and heated air would aſcend; and we have already obſerved, in treating

The Hon. Henry Cavendish, in the year 1766, discovered that inflammable air was at least seven times lighter than common air. Soon after this it occurred to Dr. Black, that if a bladder, sufficiently light and thin, was filled with this air, as the mass would be specifically lighter than the same bulk of common air, it would necessarily rise in that fluid. A few years afterwards Mr. Cavallo made some experiments on this subject, and to him belongs the honour of bringing the suggestion of Dr. Black first into public notice, in a paper which was read to the Royal Society on the 20th of June 1782. He found that the thinnest bladders were too heavy, and that China paper was permeable to the inflammable air; he proceeded therefore no further than blowing up soap-bubbles with inflammable air, which ascended rapidly to the ceiling of a room, and broke against it, and these may be termed the first inflammable air balloons which were ever exhibited.

While the art of aërostation was thus on the point of being discovered in Britain, M. M. Stephen and Joseph Montgolfier, paper manufacturers at Annonay, in France, distinguished themselves by exhibiting an aërostatic machine of considerable magnitude \*.

After

of the discoveries made upon air, that Van Helmont, a disciple of Paracelsus, gave the name of *gas sylvestre*, to that species of air which was separated from terrestrial bodies by means of fermentation, &c.

\* The principle upon which the aerial machines of Messrs. Montgolfier were constructed was that of air rarefied by heat,  
by



After various inferior experiments, a grand one was made at Annonay, on the 5th of June, 1783, before a great multitude of spectators. A flaccid bag was suspended on a pole thirty-five feet high; straw and chopped wool were burnt under the opening at the bottom; the vapour, or rather smoke, soon inflated the bag so as to distend it in all its parts, and this immense mass ascended in the air with such rapidity, that in less than ten minutes it reached the height of six thousand feet. It was carried in a horizontal direction to the distance of seven thousand six hundred and sixty-eight feet, and then descended gently on the ground.

The true cause of the ascent of these machines is, the air being rarified and expanded within them by the application of heat.

These experiments were no sooner communicated to the philosophers of Paris, than it occurred to them, that as the weight of inflammable air was not more than the eighth or tenth part of that of common air, a balloon might be inflated with this light air, which would answer all the purposes of those of M. Montgolfier, with several additional advantages. They constructed a globe of lutestring, which was made impervious to the inclosed air by a varnish of elastic gum dissolved in spirits or essen-

by which it became expanded, and therefore disposed to ascend into the common air. As in various other philosophical experiments, so in this of the two brothers, *accident* offered her precarious aid, and they had the judgment to make a proper application of a casual discovery.

tial oil. On the 23<sup>d</sup> of August, 1783, they began to fill a globe of thirteen feet diameter with inflammable air; on the 27<sup>th</sup> of the same month it was carried to the Champs de Mars, and being discharged from the cords, it arose in two minutes to the height of three thousand one hundred and twenty-three feet. When this balloon went up, its weight was thirty-five pounds less than the same bulk of common air.

The first person who ascended into the atmosphere in one of these machines was M. Pilatre de Rozier. On the 15<sup>th</sup> of October, 1783, this adventurer went up from a garden in the Fauxbourg St. Antoine in Paris, in a balloon of the Montgolfier kind, or those inflated by heat or rarefied air; its diameter was about forty-eight feet, and its height about seventy four; he ascended from amidst an astonished multitude to the height of eighty-four feet from the ground, and there kept the machine afloat during four hours and twenty-five minutes, by repeatedly throwing straw and wool upon the fire. It then descended to the ground, and the intrepid adventurer assured the spectators, that he had not received the least inconvenience during his aerial excursion.

The first balloon was exhibited in England on the 25<sup>th</sup> November, 1783, in the Artillery-ground, London, by Count Zambecari, an ingenious Italian. It was launched from that place at one o'clock in the afternoon, and at half past three was taken up near Petworth, in Sussex, forty-eight miles from

from London. It therefore went nearly at the rate of twenty miles an hour, and its descent was occasioned by a rent supposed to be the effect of the rarefaction of the inflammable air, when the balloon ascended to the rarer part of the atmosphere.

The first aerial navigator, however, who amused the intelligent, and astonished the uninformed, of this country, was Vincent Lunardi, a native of Italy; his balloon was about thirty-five feet diameter; the air for filling it was produced from zinc, by means of a diluted vitriolic acid. He ascended from the Artillery-ground at two o'clock, on the 15th of September, 1784. His balloon first took the direction of north west by west, but it soon fell into a current of air which carried it nearly north. At ten minutes past four he descended on a meadow near Ware, in Hertfordshire: during the course of his voyage the thermometer was as low as  $29^{\circ}$ , and the drops of water which adhered to the balloon were frozen.

I was myself a spectator of the flight of M. Lunardi, and I must confess I never was present at a sight so interesting and sublime. The beauty of the gradual ascent, united with a sentiment of terror on account of the danger of the man, and the novelty and grandeur of the whole appearance, are more than words can express. A delicate woman was so overcome with the spectacle, that she died upon the spot as the balloon ascended; several fainted; and the  
silent

silent admiration of the anxious multitude was beyond any thing I had ever beheld.

The most daring of all aerial voyages, however, was that performed on the 7th of January, 1785, by M. Blanchard and Dr. Jeffries, across the Straits of Dover to France. At about one o'clock, the balloon was launched near the high cliff in that vicinity; the ballast was all thrown out except three bags of ten pounds each; there being but little wind their progress was very slow; they described the prospect which they had of the southern coast of England as extremely delightful; and they were able to count thirty-seven villages. Perceiving the machine to descend, they threw out at several times all their ballast, books, &c. and at about twenty-five minutes past two, they had a most enchanting prospect of the French coast. 'We threw away,' says Dr. Jeffries, 'our only bottle, which, in its descent, cast out a steam like smoke, with a rushing noise, and when it struck the water, we heard and felt the shock very perceptibly on our car and on the balloon.' At length they passed over the high lands between Cape Blanc and Calais, when the machine rose to a greater height than it had reached during the whole voyage. They descended in safety among some trees in the forest of Guennes. In consequence of this voyage, the king of France presented M. Blanchard with a purse of 12,000 livres, and granted him a pension of 1,200 livres a year.

The

The art of navigating through the air made so rapid a progress, that within two years from its first discovery more than forty different persons performed the experiment without any material injury; and it may be justly questioned, says M. Cavallo, whether the first forty persons who trusted themselves to the sea in boats or vessels escaped so safe. We must, however, conclude this account of aerial travellers by a melancholy fact, the fate of the gallant Rozier (who had been the first aerial navigator) and of his companion, M. Romain.

This unfortunate experiment was undertaken with a view of discovering a method of raising or lowering aerostatic machines at pleasure. For this purpose a small balloon with rarefied air was attached to the larger one, which was filled with inflammable air. The small montgolfier was placed at a proper distance beneath the larger one, and it was supposed, that by increasing or diminishing the fire in the lower machine, the absolute weight of the whole would be proportionably diminished or augmented.

On the 14th of June, 1785, these gentlemen ascended in the machine, prepared as has been related. They had not been long in the air, when the balloon, filled with inflammable air, was seen to swell very considerably, and the aeronauts appeared very anxious to open the valves, and facilitate their descent, by letting the inflammable air escape. The whole machine was shortly after observed to be on fire, at the height of about three quarters

quarters of a mile from the ground. The silk, which composed the inflammable balloon, was about a minute after perceived to collapse, and the apparatus descended with such rapidity that both of the gentlemen were killed. M. P. de Rozier appeared quite dead when he reached the ground; M. Romain was found with some signs of life, but expired almost immediately after.

This dreadful catastrophe seems to have contributed to put an end to these experiments. Mr. Baldwin, of Chester, however, ascended from that city in the month of September, in the same year, and has published a very accurate and curious account of his observations during his voyage. In his ascent he observed, that the lowest bed of vapour nearest the earth appeared like pure white clouds in detached pieces, which seemed to increase as he rose. They presently coalesced, and formed, as he says, 'a sea of cotton, tufting here and there by the action of the air in the undisturbed part of the clouds.' The whole soon became an extended white floor of cloud; above which, at great and unequal distances, he observed a vast assemblage of thunder clouds, each parcel consisting of whole acres in the densest form; he compares their form and appearance to the smoke of cannon, only denser, and somewhat resembling vast masses of snow. Some clouds had motions in slow and various directions, forming a scene upon the whole truly stupendous and majestic.

The

The principles on which balloons aſcend in the atmosphere will, after what has been ſtated, be eaſily underſtood. It is a well known rule in hydroſtatics, that when a body is immerſed in any fluid, if its weight is leſs than an equal bulk of that fluid, it will riſe to the ſurface, but if heavier it will ſink, and if equal it will remain in the place where it is firſt ſtationed. On this principle, ſmoke or vapour aſcends in the atmosphere, and heated air in that which is colder. That heated air will aſcend is eaſily proved, by bringing a red-hot iron under a ſcale of a balance, which will inſtantly aſcend, becauſe the hot air, being lighter than that which is colder, aſcends, and ſtrikes the bottom, and impels it upwards; but as the density of the atmosphere decreases, on account of the diminished preſſure of the ſuperincumbent air, and the elastic property which it poſſeſſes, at different elevations above the earth, an air balloon can riſe only to a height in which the ſurrounding air will be of the ſame ſpecific gravity with itſelf. When it is in this ſituation, it will either float, or be carried in a direction with the wind or current of air which it may happen to encounter in thoſe upper regions.

The whole theory of aeroſtation depends upon this principle; for the ſame effect is produced, whether we make the air lighter, by introducing heat into it, or incloſing a quantity of gas lighter than the common air; both will aſcend on the ſame principle. Philoſophers have found by experiments, that a cubic foot of air weighs about five hundred

hundred and fifty-four grains, and that it is expanded by every degree of heat marked on Fahrenheit's thermometer, about one five-hundredth part of the whole; by heating, therefore, a quantity of air to five hundred degrees, we double its bulk when the thermometer stands at  $54^{\circ}$  in the open air, and consequently its weight will be diminished in the same proportion.

With respect to the mode of inflating a balloon with heated air, nothing more is necessary than the injection of heat into the machine, by burning combustibles under it. The air for filling the inflammable air-balloons may be obtained in several ways; but the best methods are, by applying acids to certain metals, or by exposing a quantity of water with certain mineral substances, in a close vessel, to a strong fire. M. Lavoisier, for this purpose, made the steam of boiling water pass through the barrel of a gun kept red-hot by burning coals. Dr. Priestley recommends a tube of red-hot brass, filled with small pieces of iron. By this method inflammable air is produced, the specific gravity of which is to that of common air as 1 to 13.

The best varnish for coating the silk of the balloon, in order to retain the inflammable air, is that used by M. Blanchard, which consists of elastic gum, or caoutchouc, cut small, and boiled in five times its weight of oil of turpentine, the solution being afterwards boiled for a few minutes with drying linseed oil. This varnish must be used warm. An aperture, with a valve, to which is attached  
a cord,



A cord, must be left in the top of the balloon, to prevent its bursting, by too great inflation, in the higher regions, where the air is less dense.

The only practical use hitherto discovered for balloons, is that to which the French engineers have applied them in the present war, which is, by raising them to a convenient height, to enable the engineer to reconnoitre the camp of the enemy, or a fortified place, so that he<sup>d</sup> can direct the attack to that part which is most easily assailed.

That so curious an invention should, however, terminate here, it is not easy to believe. The curiosity of the public has for the present been satiated; and the few accidents which have happened have diminished the spirit of adventure. The difficulty, indeed, of regulating the course of these aerial machines seems an almost insurmountable bar to their general utility. But who will presume to set bounds to the ingenuity and courage of man? The first mortal, who committed himself to the waves on a mishapen raft, had probably no suspicion of even those trivial improvements which were soon to succeed; and the art of navigation was long known, before the mariners compass enabled the daring but scientific genius of a Columbus to traverse the vast expanse of the Atlantic ocean.